PB83-251629

Field Assessment of Site Closure, Boone County, Kentucky

EMCON Associates, San Jose, CA

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Aug 83

U.S. Department of Commerce
National Technical Information Service
NTIS

PB83-251629

EPA-600/2-83-058
August 1983

FIELD ASSESSMENT OF SITE CLOSURE, BOONE COUNTY, KENTUCKY

by

EMCON Associates
San Jose, California 95112

Contract No. 68-03-2824/02

Project Officer

Dirk Brunner
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA-600/2-83-058	2.	3. RECIPIENT'S ACCESSION NO. PB83 251629
4. TITLE AND SUBTITLE FIELD ASSESSMENT OF SITE CLOSURE-BOONE COUNTY, KENTUCKY		5. REPORT DATE August 1983 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) EMCON Associates		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS EMCON Associates 90 Archer Street San Jose, California 95112		10. PROGRAM ELEMENT NO. BRD1A 11. CONTRACT/GRANT NO. 68-03-2824
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 8/79 - 6/81 14. SPONSORING AGENCY CODE EPA/600/14
15. SUPPLEMENTARY NOTES Contact: Robert E. Landreth 513/684-7871		

16. ABSTRACT

The current project was undertaken before the scheduled site closure to obtain information useful to designers of future landfill facilities. Information was developed on cover soils, refuse, leachate collection systems, lining materials, and contaminant migration from the test cells. To examine and recover cell components, exploratory excavations were made through the refuse and base liners. Each of the cell elements (cover, refuse, liners, etc.) were thoroughly documented, and samples underwent extensive testing. The project included the recovery and detailed inspection of clay and synthetic liners that had been exposed to leachate for approximately 9 years. Both field and laboratory testing showed that little degradation of the liner materials had occurred during these years of service. Chemical analyses of soils above and below the liners indicated that there had been no migration of leachate through these materials. The physical appearance of the refuse was similar in all excavated cells and showed little vertical difference. Decomposition was limited primarily to food wastes. Moisture tended to run along the surface of the clay liner in Test Cell 1. Isolated incidences of gravel cementation in the leachate drain were found in the upper drain of that cell.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED 20. SECURITY CLASS (This page) UNCLASSIFIED	21. NO. OF PAGES 73 22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

DISCLAIMER

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Contract No. 68-03-2824 to EMCON Associates. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community. A field investigation of landfill performance was conducted to develop information on cover soils, refuse, leachate collection systems, lining materials, and cotaminant migration from test cells. This information will be useful in designing future landfill facilities to minimize the potential for pollution.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

ABSTRACT

Landfill performance was investigated before the closure of a 4-ha (10-acre) experimental landfill site located in Boone County, Kentucky. The site contained a field-scale landfill and four smaller test cells filled with compacted municipal solid waste. From 1970 to 1980, the landfill was operated by the U.S. Environmental Protection Agency (EPA) to monitor gas and leachate production. The current project was undertaken before the scheduled site closure to obtain information useful to designers of future landfill facilities.

Information was developed on cover soils, refuse, leachate collection systems, lining materials, and contaminant migration from the test cells. To examine and recover cell components, exploratory excavations were made through the refuse and base liners. Each of the cell elements (cover, refuse, liners, etc.) was thoroughly documented, and samples underwent extensive testing.

The project included the recovery and detailed inspection of clay and synthetic liners that had been exposed to leachate for approximately nine years. Both field and laboratory testing showed little degradation of the liners and no leachate migration through these materials. The physical appearance of the refuse was similar in all excavated cells and showed little vertical difference. Decomposition was limited primarily to food wastes. Isolated incidences of gravel cementation were found in the upper leachate drain of one cell.

This report was submitted in fulfillment of Contract No. 68-03-2824/02 by EMCON Associates under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period August 1980 to June 1981, and work was completed as of March 1982.

CONTENTS

Foreword iii
Abstract iv
Figures. vi
Tables vii
Metric Conversion Factors. viii
Acknowledgment ix

1. Introduction 1
2. Conclusions and Recommendations. 3
3. Description of Test Cells and Conditions Immediately Before Closure. 6
   Test Cell 1 6
      Description. 6
      Closure Investigation. 8
      Cover Soils. 8
      Refuse 10
      Microbial Assays 17
      Leachate Collection System 21
      Liners 23
      Subsoils 30
   Test Cells 2A, 2B, and 2C 30
      Description. 30
      Test Cell 2B 34
      Test Cell 2C 36
   Test Cell 2D. 36
      Description. 36
      Cover Soil 39
      Refuse 39
      Drainage Soil. 45
      Liner. 45
      Subsoils 48

References 56
Appendices 57

A. Procedures for Physical Testing and Soil/Refuse Samples. 57
B. Procedures Used in Chemical Testing of Soil Samples. 60

FIGURES

Number		Page
1	Site layout plan	2
2	Layout and sampling locations for TC-1	6
3	Leachate collection system for TC-1.	7
4	Moisture content in TC-1 refuse at various depths.	11
5	Refuse density at different depths in TC-1	14
6	Refuse density and permeability.	16
7	Grain size analysis of the TC-1 upper collector.	22
8	Grain size analysis of the TC-1 lower collector.	24
9	Chemical analysis of clay liner in TC-1, Location E.	26
10	Chemical analysis of clay liner in TC-1, Location G.	27
11	Test cell construction details for TC-2A, 2B, and 2C	33
12	Grain size analysis for collector sand in TC-2B.	37
13	Test cell construction details for TC-2D	38
14	Sampling locations for TC-2D	40
15	Cover soil and berm details for TC-2D.	41
16	Liner uplift details for TC-2D	51
17	Grain size analysis for sand blanket in TC-2D.	53
18	Chemical analysis of collector and subsoils in TC-2D	54

TABLES

Number		Page
1	Soil Testing Data for Cover Soil in T-C 1.	9
2	Refuse Moisture Content in TC-1.	12
3	Density of Refuse in TC-1.	13
4	Permeability of Refuse in TC-1	17
5	Level of Fecal Indicators in Solid Waste and Leachate From TC-1 After 9 Years.	20
6	Soil Testing Data for Clay Liner in TC-1	25
7	Properties of Leachate-Exposed CSPE and LPDE from TC-1	29
8	Comparison of CSPE from TC-1 with Two Unsupported Sheetings.	31
9	Soil Testing Data for Subsoils from TC-1	32
10	Soil Testing Data for TC-2B and 2C	35
11	Soil Testing Data for Cover Soil in TC-2D.	42
12	Refuse Test Data for TC-2D	43
13	Properties of Leachate-Exposed and Weathered CPE Samples	47
14	Comparison of Leachate-Exposed and Weathered CPE Samples	49
15	Comparison of CPE in TC-2D with Matrecon Liner No. 12.	50
16	Analysis of Water Under TC-2D Liner.	52
17	Soil Testing Data for Subsoils in TC-2D.	55

METRIC CONVERSION FACTORS

To convert from	To	Multiply by
cubic foot (ft^3)	cubic meter (m^3)	28.32
cubic foot/minute (ft^3/min)	cubic meter/second (m^3/sec)	0.0004719
foot (ft)	meter (m)	0.3048
gallon (gal)	liter (l)	3.785
gallons per minute (gal/min)	liters per second (l/sec)	0.0631
inch (in)	centimeter (cm)	2.54
inch (in)	millimeter (mm)	25.4
pound force (lb)	newton (N)	4.448
pound mass (lb)	kilogram (kg)	0.4536
pounds per cubic foot (lb/ft^3)	kilograms per cubic meter (kg/m^3)	16.019
pounds per cubic yard (lb/yd^3)	kilograms per cubic meter (kg/m^3)	0.5933
square foot (ft^2)	square meter (m^2)	0.0929

ACKNOWLEDGMENTS

In addition to describing the results of the field investigation undertaken by EMCON Associates, this document presents the findings of several subcontractors: Matrecon, Inc. (liner testing sections), R.N.K. Environmental (solid waste analytical procedures), PEDCO Environmental (analytical testing), Dr. P.V. Scarpino, Department of Civil and Environmental Engineering, University of Cincinnati (bacteriological analyses).

SECTION 1

INTRODUCTION

Landfill performance was investigated just before the closure of an experimental landfill site in Boone County, Kentucky. The object was to obtain information useful to designers of future landfill facilities.

The 4-ha (10-acre) trace contained a field-scale landfill (Test Cell 1) and four small test cells (Test Cells 2A, 2B, 2C, and 2D) filled with compacted municipal solid wastes (see Figure 1). Known as the Boone County Field Site (BCFS), the landfill is located at the top of a ridge five miles west of the City of Walton in northern Kentucky. From 1970 to 1980, the U.S. Environmental Protection Agency (EPA) operated the site to monitor gas and leachate production. Results of these original monitoring projects are presented in two EPA documents[1,2] and the proceedings of a research symposium[3].

The present project examined the test cells just before the site was closed to develop information on cover soils, refuse, leachate collection systems, lining materials, and contaminant migration from the test cells. Exploratory excavations were made through the refuse and base liners to examine and recover cell components. Each of the cell elements (cover, refuse, liners, etc.) was thoroughly documented, and samples underwent extensive testing.

The body of this report fully describes the test cells and the conditions found before closure of the BCFS. Detailed procedures are presented in the appendices.

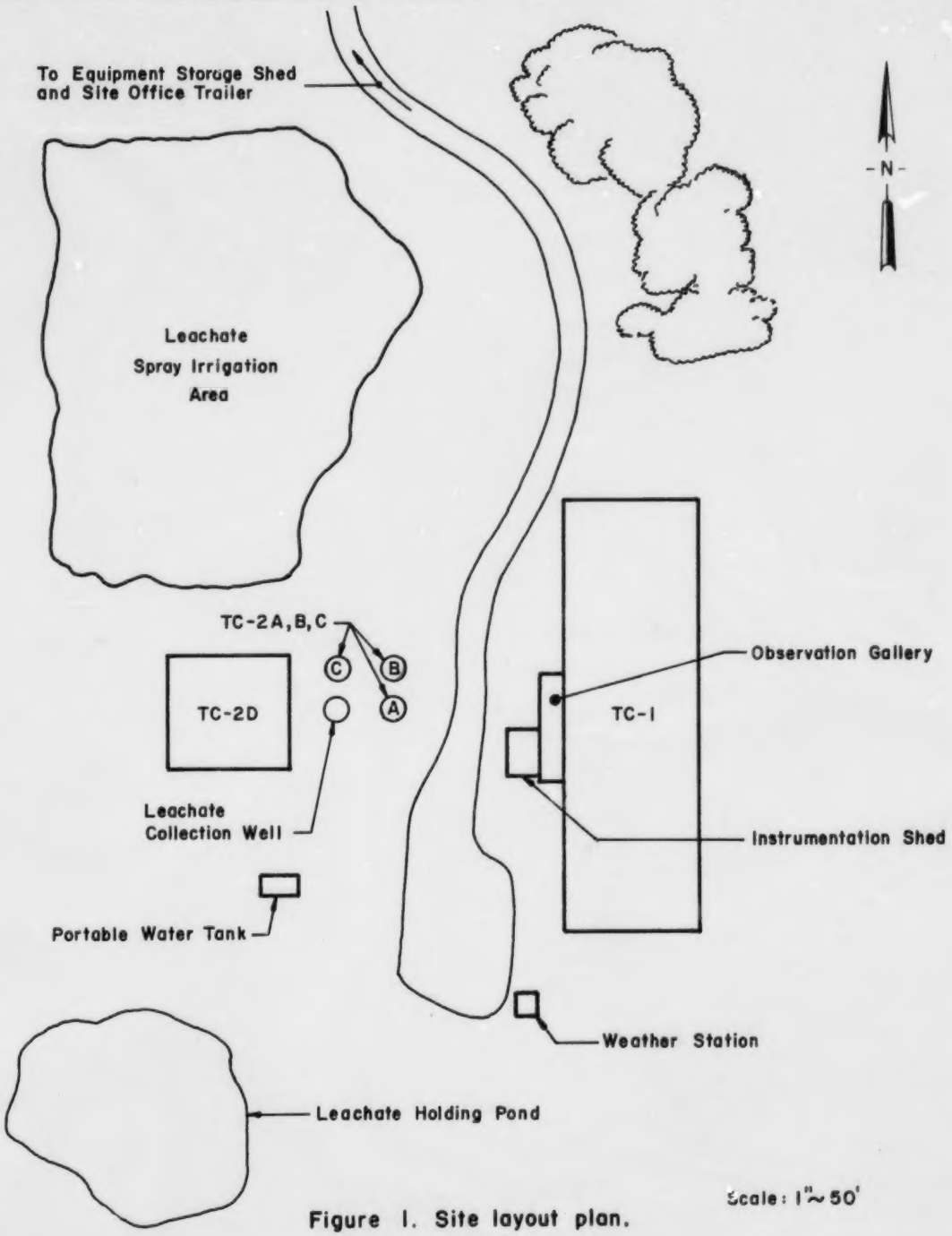


Figure 1. Site layout plan.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The results of field observations and testing of the leachate collection facilities, liners, and soil associated with the test cells may be summarized as follows:

Liners

TC-1--

- The clay liner in Test Cell 1 (TC-1) provided effective leachate containment. Chemical analysis and physical appearance indicated leachate penetration was limited to the first 12 to 14 in. (30 to 35 cm).

- Although the chlorosulfonated polyethylene (CSPE) in TC-1 was not in direct contact with full-strength leachate, it was quite swollen. The liner's retention of original properties after exposure to leachate could not be determined because of lack of data on the original liner, but its properties after exposure were reasonable compared with unexposed materials.

- A low-density polyethylene (LDPE) liner sample from TC-1 that was in direct contact with full strength leachate showed little swelling. Its properties appeared normal for a LDPE 6 to 7 mils (0.15 to 0.17 mm) thick. Observation of the material during removal indicated no punctures or tears.

TC-2D--

- The synthetic liner in Test Cell 2D (TC-2D) was effective in containing leachate within the test cell. No significant change occurred in the chemical quality of the sand below the liner.

- Recovered samples of the chlorinated polyethylene (CPE) liner from TC-2D were quite swollen as a result of exposure to leachate, but testing indicated that the physical properties of the liner samples (tensile strength, tear resistance, hardness, and puncture resistance) were relatively good. No data on comparable samples of unexposed CPE liners

were available for calculating the degree of change in physical properties. But based on 30 mil (0.76 mm) CPE liners that were manufactured by the same firm and fabricated at approximately the same time as the project samples, the retention of properties of the liner samples ranged from 60% to 90% of original values.

Drains

- The sand drain in the base of TC-2D provided efficient dewatering of the refuse pit. By contrast, perched water was encountered in TC-1 overlying the clay liner. Migration to the central drain in TC-1 appeared to be sluggish.

- Plugging of gravel drains was minimal. Gravel clasts were occasionally coated with a black discoloration, especially in the upper drain of TC-2D. The most significant observation was cementation of a short section of the upper gravel drain in TC-1. The cementatious material appeared to be iron carbonate (siderite).

Refuse

- Very little degradation had occurred in the wastes uncovered during the investigation. Newspapers buried for 10 years were still legible, and grass clippings were still green. There was a noticeable absence of food wastes except for a few well-isolated (plastic wrapped) bags containing starchy materials.

- Laboratory tests of the moisture content of the refuse showed values to be fairly consistent throughout the waste fill, ranging from 43% to 63% on a wet-weight basis.

Pathogens

- High microbial counts were found in the leachate obtained within the landfill and high fecal-indicator* levels were present in the landfilled solid wastes. Microbes can apparently survive within the landfill for long periods--in this case, more than nine years.

- All levels of the landfill seemed to offer environmental conditions and substrata for fecal-indicator bacteria. Good conditions for methane production were also observed at all levels of the landfill; the oxygen-utilizing bacteria had created anaerobic conditions within 1 to 2 ft (30 to 60 cm) of the soil surface.

RECOMMENDATIONS

Based on the findings of this study, the following future work is recommended:

*Total and fecal coliforms and fecal streptococci.

- Additional evaluation should be conducted of liners that have been exposed to solid wastes over an extended period to determine the long-term exposure effects.

- Determinations should be made of (1) the origin of the pathogens and fecal indicators, and (2) the mechanisms and dynamics of pathogen and fecal indicator survival. This information is needed for other assessments of the long-term survival of pathogens and the potential health threat that would be posed if pathogens were mobilized from landfills and entered surface or groundwater supplies.

SECTION 3

DESCRIPTION OF TEST CELLS AND CONDITIONS
IMMEDIATELY BEFORE CLOSURE

TEST CELL 1

Description

TC-1 was a trench-type, field-scale sanitary landfill 149 ft (45.4 m) long, 30 ft (9 m) wide, and approximately 10 ft (3 m) deep (Figure 2). The trench was excavated with vertical sidewalls and ramps on both ends, at a slope of approximately 1:7 (vertical:horizontal). The middle 50 ft (15 m) section of the trench was sloped approximately 7% to the transverse center line. A below-ground observation unit was constructed adjacent to the west sidewall of the excavation for collection of leachate samples from drains at the base of the fill.

The central portion of the base of the cell was covered with a 30-mil (0.76 mm) chlorosulfonated polyethylene (CSPE) liner (Hypalon), 30 by 50 ft (9 by 15 m) long. A clay soil liner 18 in. (45 cm) thick was placed directly above this synthetic liner, and a two-layer drain system was constructed to collect leachate migrating along the top of each liner (Figure 3).

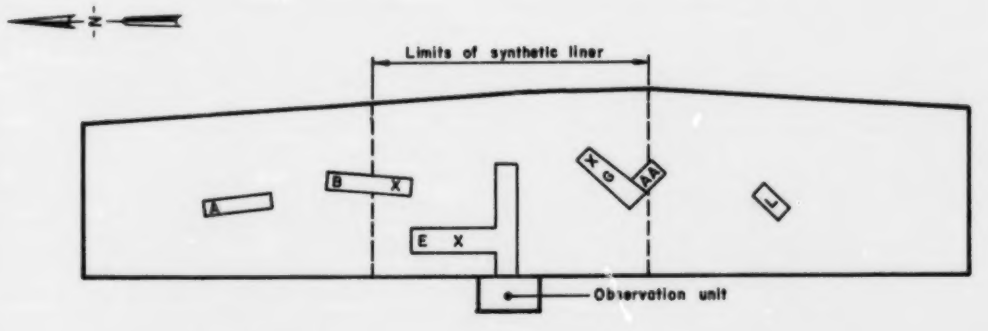
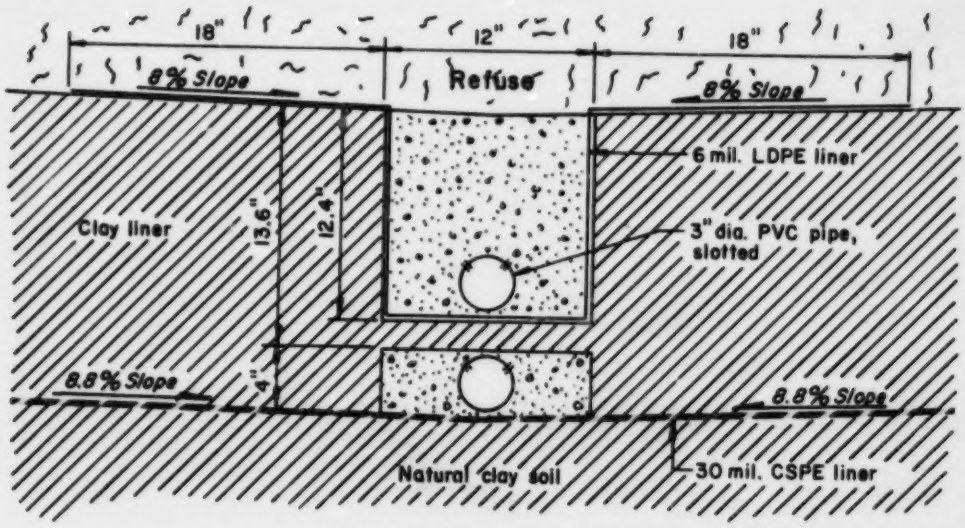
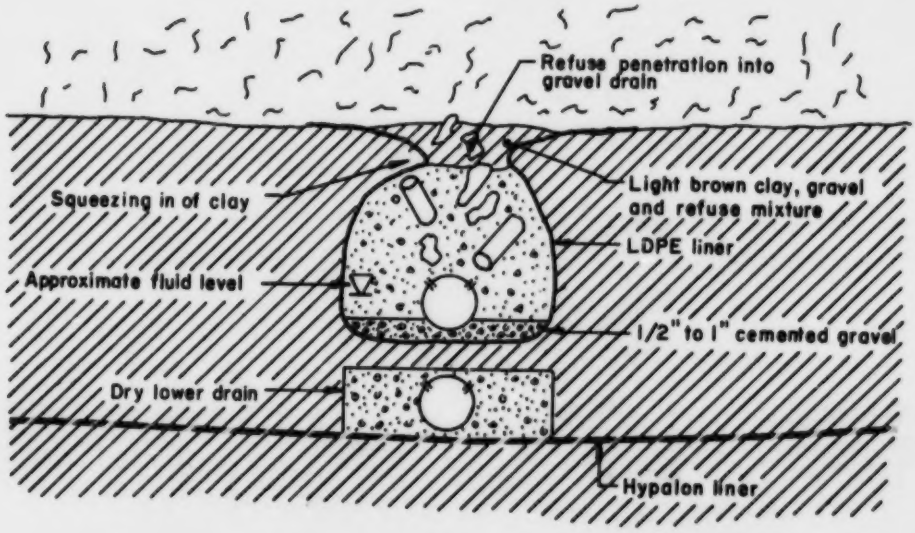


Figure 2. Layout and sampling locations for TC-1.



(a) As-built construction details for cross section at observation bulkhead



(b) Cross section as exposed 8 ft. from observation bulkhead

Figure 3. Leachate collection system for TC-1.

The drain system consisted of a slotted collection pipe along the transverse center line of the cell directly above the sheeting and a second pipe in a trench installed in the top 13 in (32 cm) of the clay liner. The trench was lined with a 6-mil (0.15-mm), low-density polyethylene (LDPE) strip. The purpose of this second pipe was to prevent short circuiting of the leachate to the lower pipe. The space around both of the pipes was filled with clean silica gravel.

Refuse was unloaded on one of the ramps, spread in 2-ft (60-cm) lifts, and compacted with a crawler-type tractor. A total volume of 869 yd^3 (794 m^3) of refuse was placed in the test cell. Measurement/observation probes were put in place as the test cell was constructed. Both thermistors and thermocouples were installed to determine temperature. Settlement plates and monuments were positioned at various depths and locations within the cell. Twenty-five gas probes were installed at various depths and locations within the landfill and in adjacent undisturbed soil.

Closure Investigation

The closure investigation was conducted by means of seven exploratory trenches constructed in the cell. Three of these (B, E and G) penetrated the refuse pile and liners to the subsoil beneath the landfill (Figure 2).

Cover Soils

TC-1 was capped with silty clay soil ranging in thickness from 24 to 36 in. (60 to 90 cm), based on direct measurements made in three excavations across the cell. The surficial layer of cover soil was light brown, contained abundant fine grass roots, and had a noticeably higher moisture content than underlying horizons. Clods of soil were easily removed by hand during excavation. The surficial zone ranged in thickness from 2 to 9 in. (5 to 23 cm), with 7 to 8 in. (18 to 20 cm) being typical.

Below the root-weathered surficial zone, the cover soil decreased in moisture content, became tan in color, and increased in strength. Shoveling and hand augering were very difficult in this dense layer. Within 2 to 3 in (5 to 8 cm) of the refuse, moisture content increased, and gray-colored areas occurred intermittently. There was little or no penetration of cover soil into the underlying refuse.

Laboratory soil testing confirmed that cover soils were fine-grained and classified as CL (clay of low plasticity) by the Unified Soil Classification System (see Table 1). Grain size analysis revealed that most soil particles (average 81%) fell into the silt size range (ASTM-ASCE grain size scale) and that the sand content was 5% or less. In-place dry density of cover soil samples ranged from 91 to 101 lb/ft^3 (1458 to 1618 kg/m^3) compared with a previously reported placement value of 97 lb/ft^3 (1554 kg/m^3).

TABLE 1. SOIL TESTING DATA FOR COVER SOIL IN TC-1

	Location A[a]	Location G	Location L
Sieve analysis[b]			
clay, %	11	14	17
silt, %	85	83	78
sand, %	4	3	5
Liquid limit, %	35	34	36
Plasticity index, %	12	12	13
Unified soil classification	CL	CL	CL
Moisture content, %	20	23	25
Dry density, lb/ft^3	100	101	91
Permeability, cm/sec			
in-place	3×10^{-5}	5×10^{-5}	7×10^{-5}
laboratory	9×10^{-7}	1×10^{-6}	2×10^{-5}

[a]See Figure 2 for locations of excavations.
[b]ASTM-ASCE grain size analysis.

The permeability of the cover soil was determined by both in-place field and laboratory procedures at Locations A, G and L (Figure 2). Test methods are described in Appendix A. The permeability values ranged from 8×10^{-7} to 2×10^{-5} cm/sec for laboratory tests and from 3×10^{-5} to 7×10^{-5} cm/sec for field tests.

Some potential exists for relatively rapid infiltration along fracture planes noted during cell excavation. After a period of drying, exposed thicknesses of cover soil tended to slough into excavations along nearly vertical and well-defined planes. In one case, heavy iron staining indicative of fluid migration was noted on a vertical fracture surface extending completely through the cover soil.

Relatively tight cover soil permeabilities are desirable in order to keep infiltration to the refuse at a minimum. In general, permeability determinations indicated that the cover at the BCFS was constructed so as to achieve that goal. Field determinations of permeability were approximately 50 times greater than laboratory determinations. The apparent tightness of the cover is offset by the observed presence of a vertical seepage plane penetrating the full depth of the cover. The presence of a similar seepage plane may explain the apparent outlier of the laboratory determination -- 200×10^{-7} cm/sec.

The plane also indicates that over an extended period of time, soil structuring may increase the permeability of cover systems.

Refuse

General--

Four test pits were excavated in Locations AA, B, E and G (Figure 2) to expose a cross-section of the refuse. The reasonably well preserved condition of the waste material was remarkable. Newspapers approximately 10 years old were quite legible and only slightly discolored. Metal cans (beer, soda, etc.) were only slightly rusted, and labels were only slightly discolored. Grass clippings were bright green. With the exception of corncobs, food material was reduced to a brittle residue.

Very little odor was detected from the excavated refuse, and minimal odor was noticed in the trenches excavated into the refuse. Gas levels were monitored before the trenches were entered, but any gases present were dissipated rapidly by natural breezes through the trenches and, if needed, by mechanical air blowers.

The most extensive refuse degradation was observed at Location E just above the clay liner. At this depth, 8 to 9 feet (2.4 to 2.7 m), the refuse was saturated. A 1- to 3-in (2.5 to 7.6 cm) layer of malodorous, dark black debris overlay the upper surface of the clay liner. This dark material was composed primarily of sludge containing wood and plastic fragments. When newsprint was found, it was covered with a black gritty coating and nearly illegible. Metal was brittle and corroded. A thin (<1 mm) sand layer was found immediately above the clay liner. These conditions were not encountered elsewhere in the cell.

Moisture Content--

The refuse was moist to the touch, and results of laboratory tests (Table 2) showed fairly consistent values of 43% to 63% moisture throughout the refuse on a wet-weight basis.

The data collected indicate greater variability in moisture content near the surface and slightly higher moisture content near the bottom (Figure 4). These trends are not statistically significant, however.

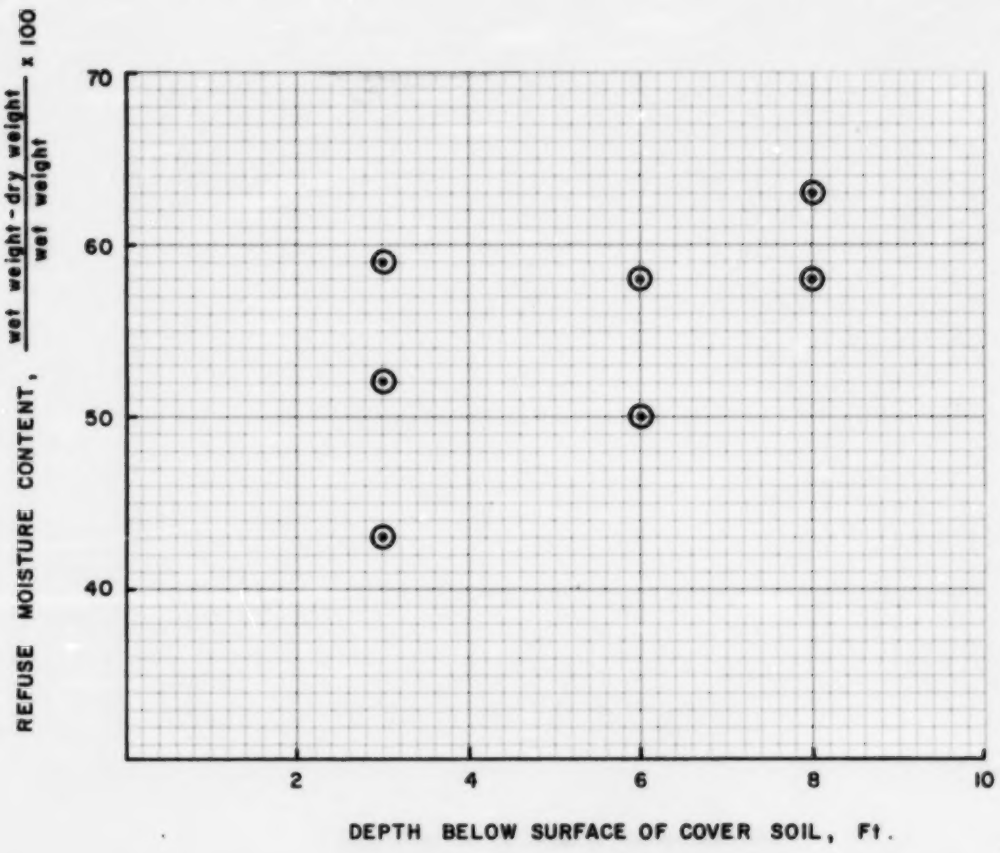


Figure 4. Moisture content in TC-1 refuse at various depths.

TABLE 2. REFUSE MOISTURE CONTENT IN TC-1

Trench (See Figure 3)	Depth[a] (ft)	(m)	Moisture content[b] (%)
A	3	0.9	43
AA	3	0.9	52
AA	6	1.8	58
AA	8	2.4	63
B	3	0.9	59
B	6	1.8	50
B	8	2.4	58
			Mean = 55

[a]Depth below ground surface, top of soil cover.
[b]Moisture Content = (wet weight - dry weight)/wet weight.

Chemical Analysis--

Samples of refuse were collected at sample Locations E and G and were processed. The objective of this assay was to determine whether chemical composition varied vertically, as might be expected in a down-flow, single-pass reactor. The results were inconclusive--possibly because of the limitations of the sampling procedures and of analytical precision and accuracy, but more likely because of the relatively shallow depth of the refuse after nine years of leaching and biological activity. This interpretation is consistent with the results of the visual inspection during excavation, which failed to indicate any observable difference in refuse appearance. Chemical analyses did, however, show that concentrations of K, Ca, and Mg tended to increase with depth. TKN showed the opposite trend.

Leachate Production--

Nearly continuous leachate seepage from refuse was encountered in a saturated zone approximately 12 in (30 cm) above the underlying clay liner in Trenches AA, B, E and G and above the clay subsoil in Trench A. Seepage rates were estimated to be 2 to 3 gal/hr (7 to 11 l/hr) from a trench 8 ft (2.4 m) long and 3 ft (0.9 m) wide. Leachate partially filled excavations in the central portion of the cell, and this leachate was retained during the entire week that the trenches remained open. Thus, it appears there was a resistance for water to move toward the drain in the central portion of the cell.

Most leachate was light in color and only moderately turbid. In contrast, intermingled seeps of rust-colored fluid were observed exiting through discrete scattered points in the saturated refuse. These darker fluids had a noticeable odor and formed a sheen on ponded seepage. Two or three of these concentrated seepage zones were encountered in each trench.

Density--

Seven in-place density determinations were made of the refuse during closure by the test method described in Appendix A. The mean wet refuse density was determined to be 1,940 lb/yd^3 (1151 kg/m^3) and the mean dry density 1,260 lb/yd^3 (748 kg/m^3). Initial placement estimates calculated from refuse weights and surveyed volumes were 1,000 lb/yd^3 (593 kg/m^3) mean wet density and 725 lb/yd^3 (430 kg/m^3) dry density. Field test results are summarized in Table 3 and Figure 5.

TABLE 3. DENSITY OF REFUSE IN TC-1

Trench	Depth below ground surface (ft)	(m)	Dry density (lb/yd^3)	(kg/m^3)	Wet density (lb/yd^3)	(kg/m^3)
A	3	0.9	1380	770	1960	1160
AA	3	0.9	1230	730	1970	1165
AA	6	1.8	1150	680	1820	1080
AA	8	2.4	960	570	1560	925
B	3	0.9	1150	680	1830	1085
B	6	1.8	1610	955	2420	1435
B	8	2.4	1320	783	2090	1240
Mean			1260	748	1940	1151
Initial Placement			725	430	1000	594

The dramatic increase in refuse densities from the time of initial placement to site closure requires closer examination. The decomposition of refuse releases material from the landfill by means of gas emission or leaching. Such releases may account for a 10% apparent decrease in mass and thus in density. In addition, the refuse generally settles or reduces in volume as a result of the decomposition processes and their effects on the physical characteristics of refuse. The relatively small reduction in mass in conjunction with a larger decrease in volume would indeed result in a greater density than when the refuse was originally placed. But the volume reductions, particularly with densities that were high at initial placement, would be expected to be less than 30% -- not enough to account for the 70% observed increase in density.

Another explanation of the increased density may be the measurement techniques used. Density is a ratio of weight and the volume it occupies. Weight is relatively easy to measure accurately -- generally within a few percent (and frequently less than 1%) of the true value. This is true for both the refuse weighed in trucks during construction and for the refuse weighed in plastic bags during the closure investigation.

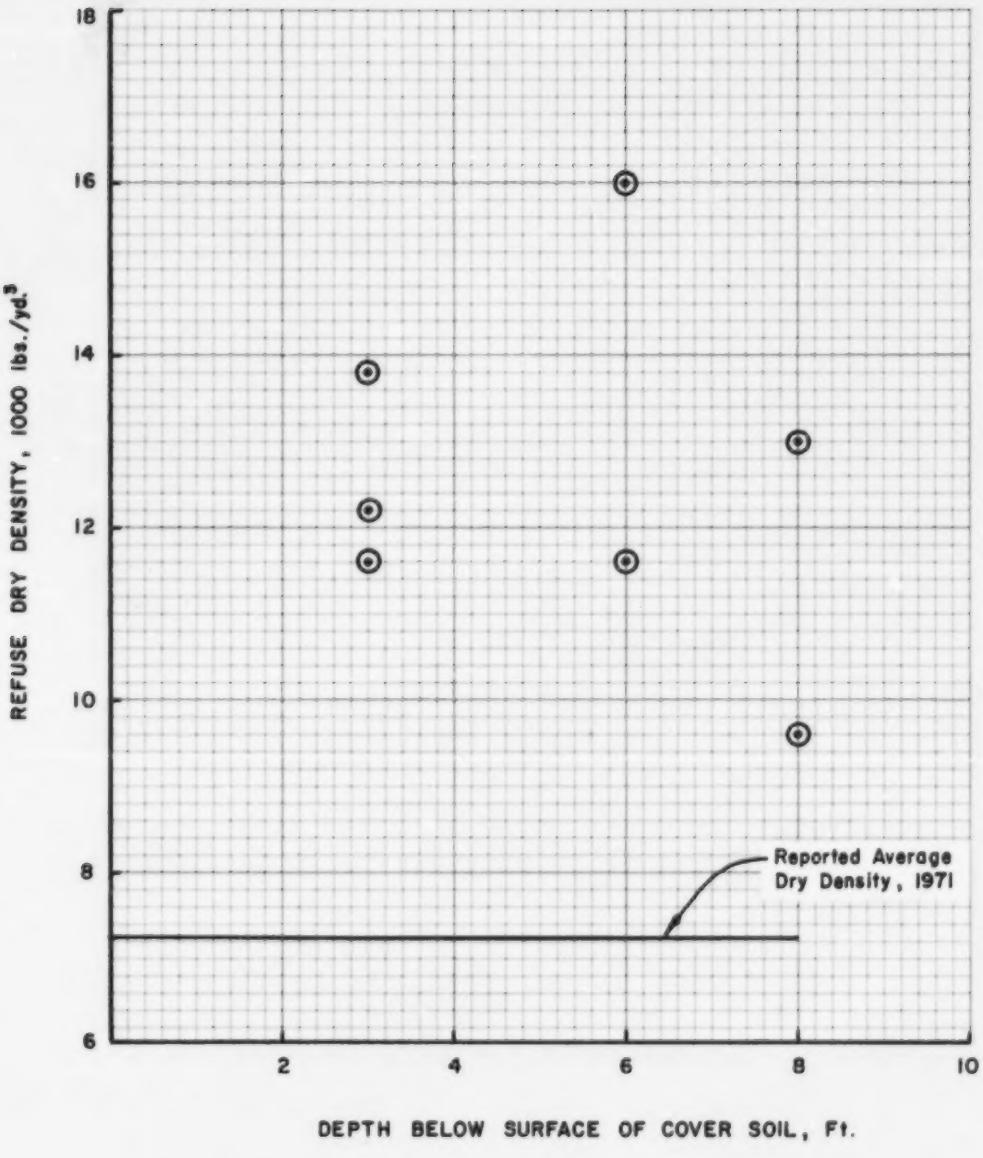


Figure 5. Refuse density at different depths in TC-1.

Volume estimates are typically more difficult. The landfill was constructed in a relatively well-defined excavation; however, the volume of refuse excavated during the closure investigation was less well defined, and irregularities account for a greater percentage of the volume than is true of soil excavations. Filling the irregular void with a fluid material of known specific gravity (e.g., water) is therefore advisable to determine the volume. Unfortunately, the plastic sheet used in such measurements restricts the ability of the chosen material to flow into all of the voids from which refuse was removed. As a consequence, the volume estimates obtained during closure are susceptible to underestimation. If the volume estimates made for TC-1 were underestimated, this could account for the apparent overestimation of the refuse density.

Another consideration when determining density is whether the refuse material removed during the closure investigation is a representative sample. Typically, representative refuse samples should weigh 200 to 300 lbs (90 to 130 kg), but excavation of such a large quantity is very time-consuming and costly. Since the weight measured during construction of TC-1 was the total sample, representativeness was not important. The spread of density data from the closure operation indicates a combination of difficulties with representative weight and volume measurements.

It is apparent, then, that a strong need exists for an accurate, reproducible method for determining in-place density at a reasonable cost. Compacted municipal refuse is difficult to excavate, and the void remaining is not well defined. Measuring the void volume by lining it with plastic and volumetrically filling it with water underestimates the void size, since the plastic fails to fill all of the irregularities. Filling the void with a well-defined sand would overestimate the volume because of interconnected voids that extend beyond the area occupied by the removed refuse. In addition, such procedures are expensive. Based on the results of this study, it is recommended that in-place refuse density be determined by excavating 200 to 300 lbs (90 to 130 kg) of refuse and backfilling the void with a uniformly graded pea gravel.

Permeability--

The refuse thickness was found to be 7 ft (2 m) at Location G and 6 ft (1.8 m) at Location E.

The in-place permeability of refuse was determined at seven locations, using the field test methods described in Appendix A. The mean permeability value, as determined in the field, ranged from 1×10^{-2} to 4×10^{-2} cm/sec. This value should be considered somewhat higher than the actual value because of the difficulty in creating a complete seal of the permeameters to the refuse. In addition, experience with laboratory and field permeameter observations on the cover soil indicate that permeability values measured with field permeameters are about 50 times those made by laboratory determinations. No correlation exists between refuse permeability data (Table 4) and density data (Figure 6) for TC-1, though such correlation is commonly found in soils.

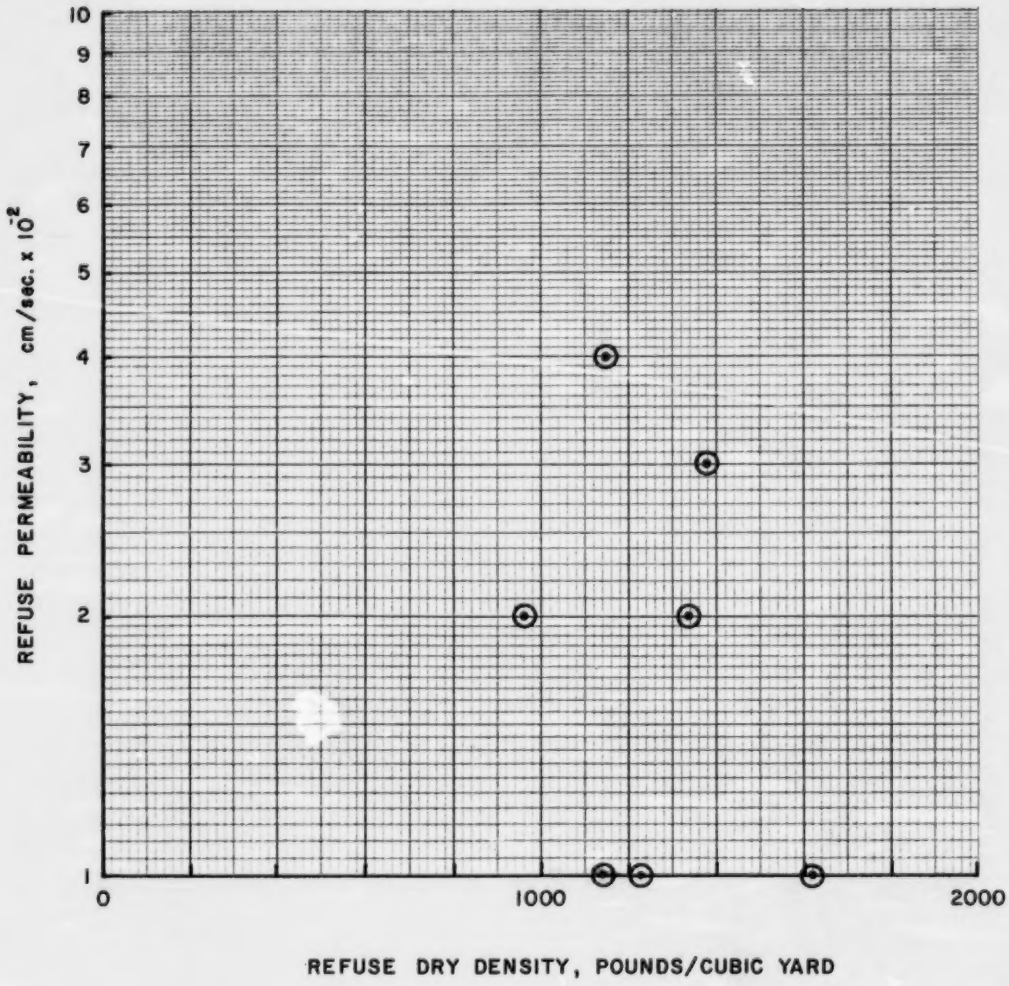


Figure 6. Refuse density and permeability

TABLE 4. PERMEABILITY OF REFUSE IN TC-1

Trench	Depth (ft)	(m)	Permeability (cm/sec)
A	3.3	1.0	3×10^{-2}
AA	4.1	1.2	1×10^{-2}
AA	5.7	1.7	4×10^{-2}
AA	7.0	2.1	2×10^{-2}
B	4.0	1.2	1×10^{-2}
B	5.6	1.7	1×10^{-2}
B	6.9	2.1	2×10^{-2}
		Mean	2×10^{-2}

Pore Water--

Analyses of the pore water and leachate indicate that concentrations of chemical components were generally higher in the pore water of the refuse than in the leachate. Pore water was obtained by compressing samples of excavated refuse stored for several days in plastic bags at 5°C, and collecting and analyzing the water released. Leachate samples were collected several days before the refuse excavation; no rainfall occurred during the intervening days. The results of the analyses can be explained by the concepts proffered by Phelps, which describe leachate generation as a mass transfer phenomenon between a stagnant water film that surrounds all refuse and water percolating the fill at a specific rate and contact time. Under this interpretation, leachate concentrations would be expected to be lower than those of pore water, if the rate of percolation exceeded the mass transfer rate.

Concentrations of constituents in the pore water generally increase with depth. The data for total solids from TC-1 best illustrate this trend (see Appendix D, Figure D-1). This observation also agrees with what was proposed by Phelps: the rate of mass transfer, and consequently concentration in the leachate, is limited by concentration gradients. As the gradient becomes smaller, fewer constituents are driven into solution toward the saturation level. Observations to this effect were expected to be more pronounced, and it was thought that chemical analysis of the refuse would confirm these observations, but the data are generally inconclusive.

Microbial Assays

Samples of cover soils, leachate, and refuse from TC-1 and from control soils 200 ft away were examined for microbiological populations (chiefly bacteria). Analyses were made for fecal indicators (total coliforms, fecal coliforms, and fecal streptococci) and for methane-producing and methane-using bacteria.

Methods for Fecal Indicators--

Leachate samples were collected from inside the landfill in sterile, glass, screw-capped bottles (2-liter) previously gassed with nitrogen to decrease the oxidation of the leachate by the air. The completely-filled sample bottles were transported in an ice chest (<10°C) to the laboratory, where they were transferred to a 5°C refrigerator and stored until they were processed.

Solid waste and soil samples were taken at depths of 0.46 to 3.96 m (1.5 to 13 ft) and placed immediately into sterile plastic bags from which the air was then squeezed. When anaerobic conditions were ultimately required, samples were placed in a GasPak jar (BBL). All samples were transported in an ice chest to the laboratory, where they were refrigerated at 5°C and processed within 24 hours.

Twenty-gram solid waste samples were homogenized in a Waring blender for 15 sec with 180 ml of distilled water (or phosphate buffer if a chemical test was to be performed) before microbial enumeration or chemical analyisis. If anaerobes were involved, nitrogen gas was added to the blender to decrease oxygen contact. The blended liquid was then analyzed as described in Standard Methods for the Examination of Water and Wastewater (1976).

Special quantitative procedures and media need to be used for finding the small number of pathogens that may occur in leachates containing huge numbers of other bacteria and fungi. The procedures used here included total and fecal coliform most probable number (MPN) tests, fecal streptococcus MPN test, and plate counts using various media. Special enrichment or depressing procedures (or both) were sometimes needed for pathogens occurring in very small numbers.

Total and fecal coliform densities were determined for all samples by the MPN procedure described in Standard Methods (1976). The five-tube technique was used in all studies.

Fecal streptococci densities were determined by the MPN procedure as described in Standard Methods[4] using the five-tube technique. M-enterococcus plate counts were also used as reported by Dudley et al[5]. With leachates containing high counts of streptococci, the plate counts gave streptococci levels that were 10 times higher than those yielded by the MPN procedure.

The ratio of fecal coliforms to fecal streptococci was used to estimate whether the pollution originated from a human or nonhuman source. A ratio of less than 0.7 is believed to indicate contamination from domesticated farm animals, whereas a ratio of greater than 4 indicates a human source[6].

Bacteria were enumerated and identified by plate counts on a variety of differential media. Gram-negative rods (coliforms and other Enterobacteriaceae species and non-Enterobacteriaceae bacteria such as the aeromonas and the vibrios were indicated on MacConkey agar. KF-Streptococcal agar was used to grow animal streptococci, and m-enterococcus agar was used to

grow streptococci from municipal sources. Standard plate count medium was used to determine the total plate counts in environmental samples. Anaerobic b[illegible]od agar was used to indicate the presence of Clostridium perfringens and to pr[illegible]de a source of isolated anaerobic bacteria. Aerobic blood agar plates were [illegible]sed as controls. Sabouraud agar was used to indicate the presence of yeast and the total mold or fungal counts. Mold inhibitory agar and mycose were used as restrictive media and were usually counted after 1 week at room temperature.

Bacteria were isolated from leachate and solid waste by two procedures: Picking well-isolated colonies from the agar plates used for enumeration, and using enrichment procedures followed by streaking the growth on differential agar plates.

Pathogenic gram-negative microbes, including the Enterobacteriaceae (coliforms, Salmonellae, Shigellae, and Klebsiellae), Acinetobacter, and Moraxella, were identified on a variety of quantitative or enrichment media.

Methods for Methane-Producing and Methane-Using Bacteria--

The soil covering the landfill was analyzed to determine the concentration of methane-using bacteria, and samples of refuse within the landfill were examined to determine the concentration of methane-producing bacteria. Procedures included the use of closed glass vials containing inocula, to which were added media containing salts and nutrients plus purified methane, carbon dioxide, and hydrogen gases, as needed. The vials were incubated on a shaker at 35°C for several weeks. Finally, the gaseous products were analyzed with gas-injection chromotography on a Perkin-Elmer 900 gas chromatograph equipped with a thermal conductivity detector.

Results and Conclusions--

High levels of fecal indicators (total and fecal coliforms and fecal streptococci were found in the leachates and solid wastes within the landfill at all depths (Table 5). Indications were that these microbes had continued to survive and reproduce for 9 years. These results were unexpected, since earlier tests of leachate from TC-1 had shown low levels of fecal idicators and fecal streptococci after 3 years, indicating that the total and fecal coliforms had died in the landfill. These earlier tests had been confirmed by laboratory tests in lysimeters filled with municipal solid waste and hospital waste.

In addition to the fecal indicators, a number of pathogens were identified in the solid waste samples from TC-1. These included Acinetobacter sp., Escherichia coli, Klebsiella pneumoniae, Moraxella sp., and Salmonella sp. Infections that can be caused by these pathogens are meningitis, septicemia, wound infection, bacillary dysentery, pneumonia, otitis, diarrhea, and gastroenteritis. Other nonpathogenic Enterobacteriaceae and related Gram-negative rod bacteria were also found. Their presence in the solid waste is significant, since they were not found in the control soils.

TABLE 5. LEVELS OF FECAL INDICATORS IN SOLID WASTE AND LEACHATE FROM TC-1 AFTER 9 YEARS

Type of sample	Samples collected at these descending levels (ft)	Fecal indicator bacteria MPN (cfu)/100g or 100 ml		
		Total coliforms*	Fecal coliforms*	Fecal streptococci+
Top Soil	1.5	240,000	3,500	980,000
MSW‡	5.0	110	<20	20,000
MSW	7.0	2,400	20	60,000
MSW	8.5	160,000	230	330,000
MSW	9.0	54,000	330	ND**
Leachate	10.0	9,200	350	110*
MSW	10.5	35,000	490	35,000*
Clay Liner	11.0	50	<20	20,000
Soil Beneath	13.0	50	<20	<20,000

* Standard Methods (1976)[4]

\+ Donnelly et al. (1980)[7]

‡ Municipal solid waste.

** Not determined.

The long-term survival of fecal indicators and pathogens poses a health threat to humans or animals who may contact contaminated leachate or groundwater. Further study is therefore required to determine the possibility of extensive groundwater contamination near all municipal solid waste landfills.

The methane analyses demonstrated that methane use in the landfill cover soil was almost identical to that of the control soil. Thus any methane that arose from biological degradation in the landfill did not increase the number of methane-using bacteria in the cover soil.

In the methane-production studies, methane-producing bacteria were found in high or significant numbers in all levels of the landfill studied--5, 7, and 8-1/2 ft. But the control soil contained these bacteria in the lowest level only, and at a concentration slightly lower than that in the landfill. These bacteria appear to be ubiquitous, to survive wherever conditions are favorable, and to metabolize where substrate is present. Thus favorable conditions for these bacteria were present in the lower level of the control soil (where oxygen concentrations were lower), and in all levels of the landfill (where oxygen-using bacteria created anaerobic conditions just a foot or two below the soil surface.

Leachate Collection System

During operation of the test site, leachate was drained from TC-1 through two collection pipes, as shown on Figure 3. The area around both pipes was backfilled with washed silica gravel.

A 20-ft (6-m) length of the upper collector, extending eastward from the collection gallery bulkhead, was exposed during cell excavation. The upper surface of the collector was partially covered with gray clay from the liner in which the drain was embedded and with a light brown silty clay of unknown origin (see Figure 3b). The light brown clay was mixed with refuse and concentrated over the axis of the drain. The light brown color tends to indicate that the clay was deposited during excavation. Refuse had also penetrated the gravel and come into direct contact with the collection pipe.

The upper drain was typically 8 to 12 in (20 to 30 cm) deep. The upper 4 in (10 cm) of gravel backfill was moist and still of a natural light color. The lower 4 in (10 cm) was saturated with an odorous dark black fluid. Gravel was stained by a thin, fine, black and rust-colored coating. Tiny particles of glass, metal chips, and sand partially filled voids in the gravel and the bottom 1/8 in (0.3 cm) contained a continuous gritty sand deposit. Approximately 50% of the gravel drain material ranged from 3/8 to 3/4 in (0.9 to 1.9 cm) in diameter. Results of sieve analysis on representative samples from the upper drain are shown in Figure 7.

Gravel was generally subrounded in shape and accepted water at a rate greater than could practicably be applied through permeameters.

Beginning 7.5 ft (2.3 m) east of the collection bulkhead, a zone of cemented gravel was encountered in the bottom 0.5 in (1.3 cm) of the upper collector. The zone of cementation appeared to extend approximately 6 ft

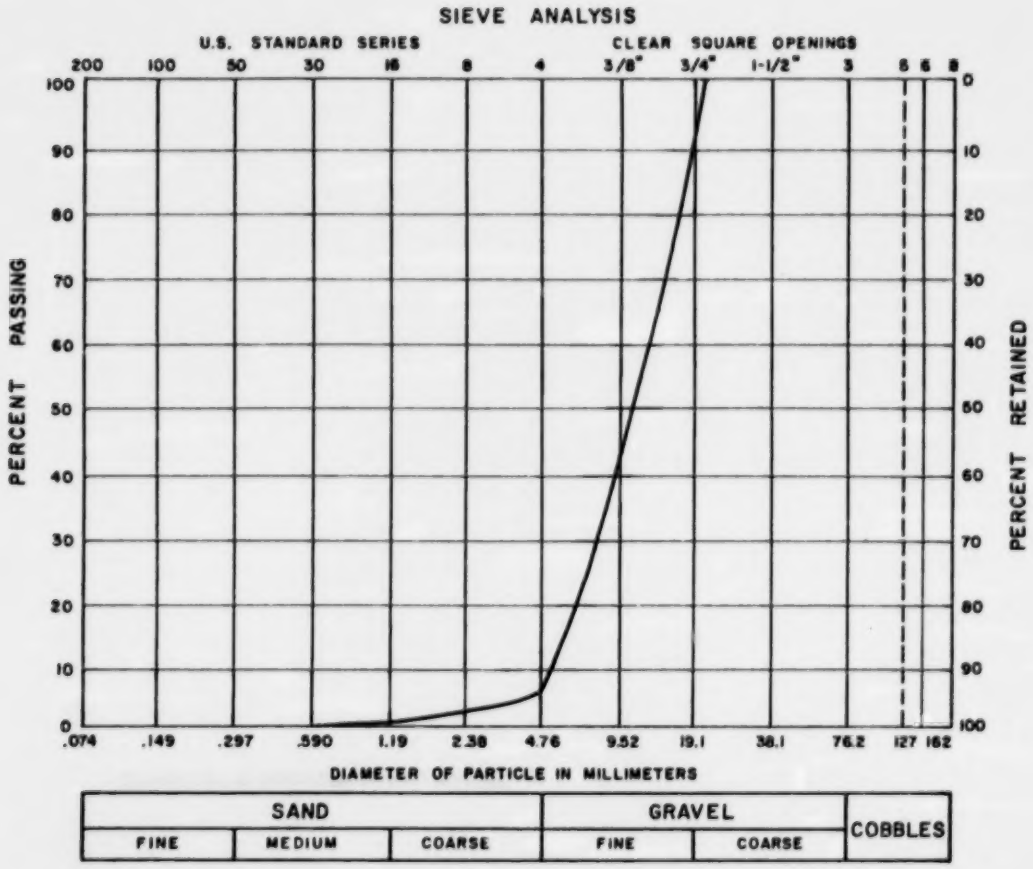

SIEVE ANALYSIS
U.S. STANDARD SERIES
CLEAR SQUARE OPENINGS
200 100 50 30 16 8 4 3/8" 3/4" 1-1/2" 3 6 6 8
PERCENT PASSING
PERCENT RETAINED
100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100
.074 .149 .297 .590 1.19 2.38 4.76 9.52 19.1 38.1 76.2 127 152
DIAMETER OF PARTICLE IN MILLIMETERS
SAND
GRAVEL
COBBLES
FINE
MEDIUM
COARSE
FINE
COARSE

Figure 7. - Grain size analysis of the TC-1 upper collector.

(1.8 m) along the length of the drain. The cementing material was analyzed by diffractometer and found to consist of a fine-grained mixture of quartz (SiO_2), rhodochrosite with a minor iron component (Mn, Fe CO_3), gypsum ($CaSO_4 - 2H_2O$), and a minor amount of illite ($KAl_2 (AlSi_3) O_{10} (OH)_2$).

The upper collector, installed in the clay liner, is separated from the lower drain by a variable thickness of clay. The clay separation ranges from 18 in (46 cm) on the east edge of the cell to 2 in (5 cm) at the collection gallery bulkhead. Within 18 in (46 cm) of the bulkhead, the clay adjacent to and under the upper gravel drain had been reduced to a soft, mottled material that was very moist, greenish-gray, and highly iron-stained. A small hole or channel measuring approximately 0.5 in^2 (1.3 cm^2) penetrated the clay 6 in (15 cm) from the bulkhead, providing a hydraulic connection between collectors. Clay against the bulkhead was very loose in places and stained a bright red, reflecting seepage along the bulkhead-clay interface and between drains. The thin 6-mil (0.15 mm) LDPE sheet underlying the upper drain near the bulkhead was found to be in good condition with no obvious tears or rips (see Figure 3).

Gravel in the lower collector, composed of 3/8- to 3/4-in (0.9- to 1.9-cm) material, was low in moisture content and unstained through its entire thickness, reflecting minimal contact with leachate. No free fluids were encountered in the lower collector. A representative gradation curve for gravel in this collector is shown in Figure 8.

Liners

Clay Liner

The clay liner between the refuse fill and the CSPE liner varied in thickness from 17 to 24 in (43 to 61 cm). The liner was composed of a slightly sandy, moderately plastic clay, with limestone rock fragments up to 10 in (25 cm) long lying parallel to the liner surface. The clay is classified as a CL by the Unified Soil Classification System, with an average liquid limit of 42 and a plasticity index of 20. Soil testing data are summarized in Table 6.

The clay liner had an average in-place dry density of 99 lb/ft^3 (1,586 kg/m^3) and moisture content of 25%. The clay exposed in excavations was light brown-gray to a depth of 12 to 14 in (30 to 36 cm), where it abruptly changed to a more natural orange-tan for the remainder of its thickness. No visual signs of cracking or channeling, nor unusual changes in texture or consistency were noted in any of the excavations.

The permeability of the clay liner was investigated by both in-place and laboratory methods. Permeability values ranged from 4×10^{-7} to 5×10^{-7} cm/sec for in-place tests; they were 2×10^{-8} cm/sec for laboratory tests. Chemical analyses were performed on selected samples of the clay liner. Extraction and test methods used for the clay analysis are described in Appendix B. Test results (Figures 9 and 10) indicate that the clay liner provided effective leachate containment. Some leachate had collected below the clay liner, but this leakage resulted from a small perforation in the clay separating the upper and lower drains, not from liner failure. The uniform contours of the perforation suggested accidental puncturing of the clay surface during cell preparation.

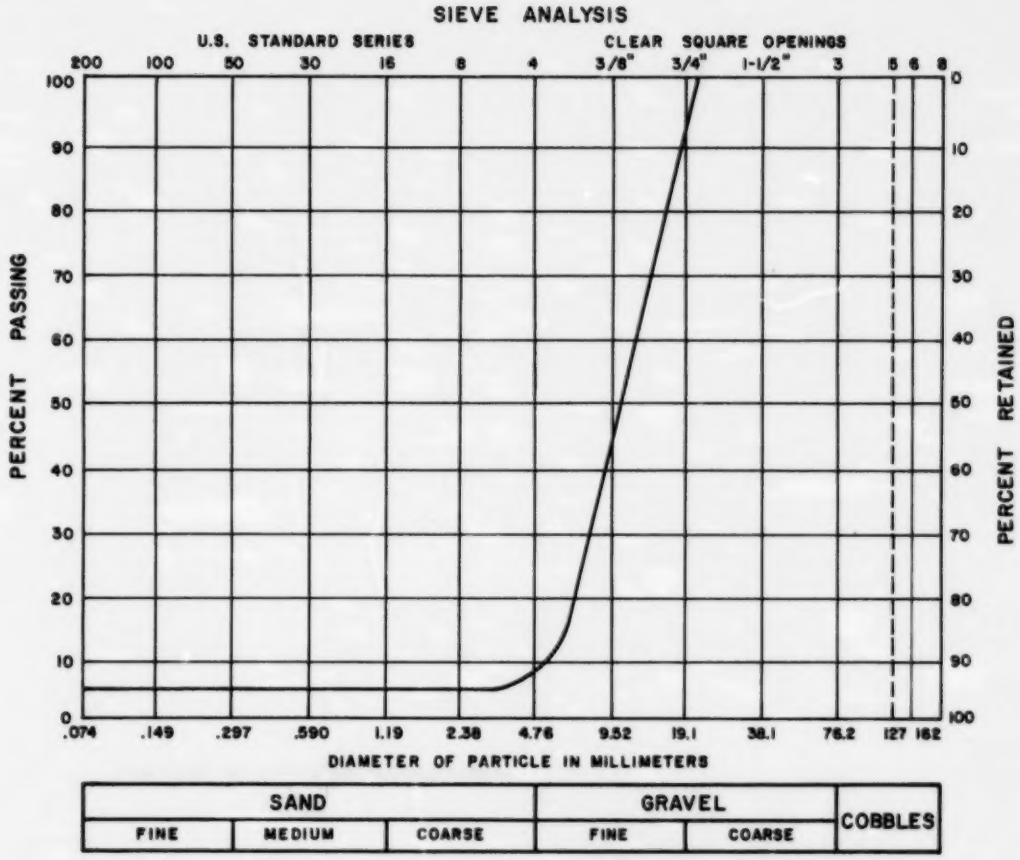

SIEVE ANALYSIS
U.S. STANDARD SERIES
CLEAR SQUARE OPENINGS
200 100 50 30 16 8 4 3/8" 3/4" 1-1/2" 3 5 6 8
PERCENT PASSING
PERCENT RETAINED
100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100
.074 .149 .297 .590 1.19 2.38 4.76 9.52 19.1 38.1 76.2 127 152
DIAMETER OF PARTICLE IN MILLIMETERS
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
COBBLES

Figure 8. - Grain size analysis of the TC-1 lower collector.

TABLE 6. SOIL TESTING DATA FOR CLAY LINER IN TC-1[a]

	Background[b]	Background[c]	Location B	Location E	Location G
Sieve analysis[d]					
clay, %	24	10	34	0	30
silt, %	70	86	54	88	62
sand, %	6	4	12	12	8
Liquid limit, %	40	46	45	44	36
Plasticity index, %	19	22	23	21	16
Unified soil classification	CL	CL	CL	CL	CL
Moisture content, %	...	...	30	23	23
Dry density, lb/ft^3	...	...	95	109	93
Permeability, cm/sec					
in-place	...	...	5×10^{-7}	4×10^{-7}	4×10^{-7}
laboratory	...	...	2×10^{-8}	2×10^{-8}	2×10^{-8}

[a]See Figure 3 for location of excavations.

[b]Sample of clay retained at time of liner placement.

[c]Sample of clay from borrow area.

[d]ASTM-ASCE grain size scale.

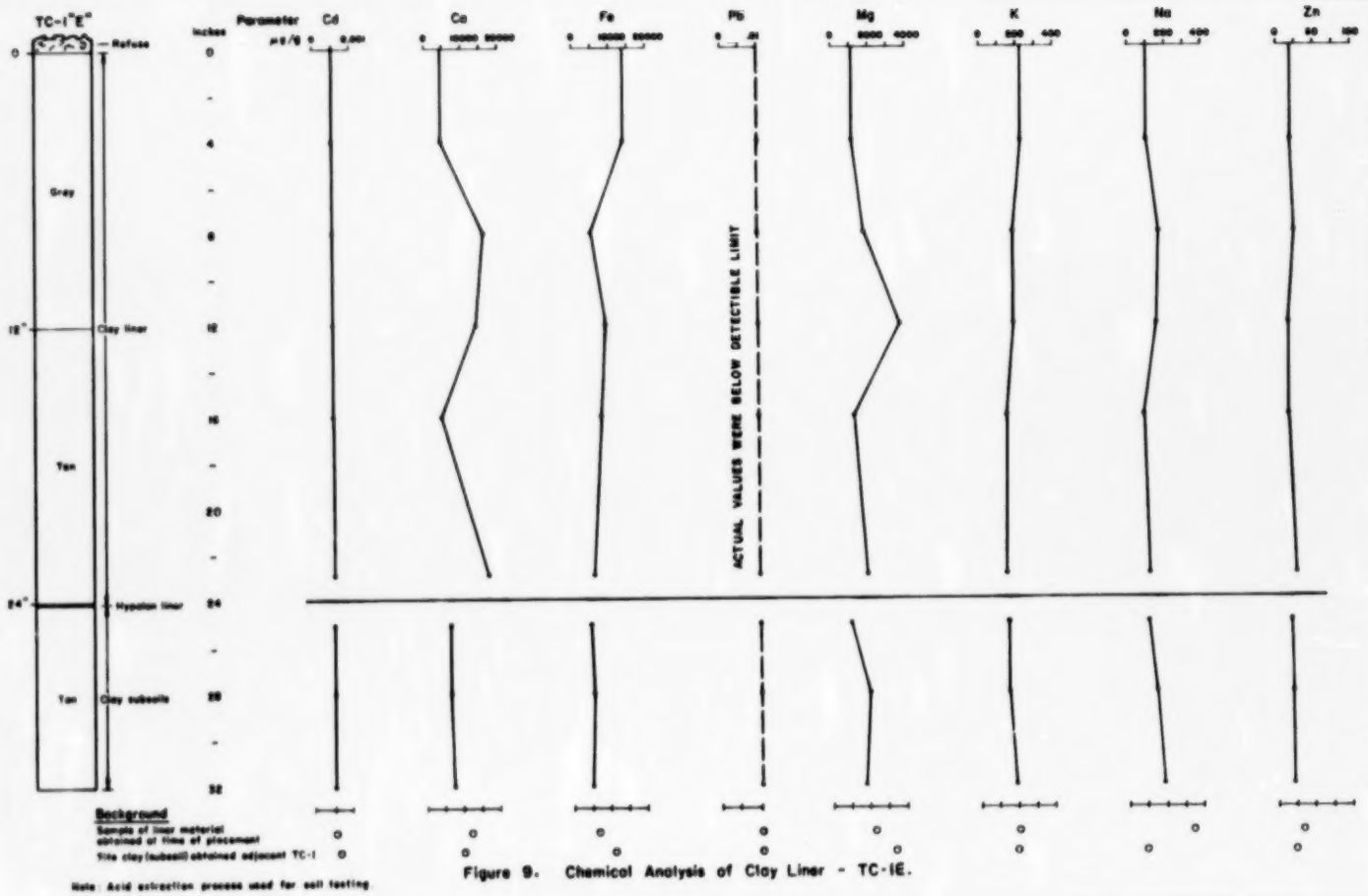
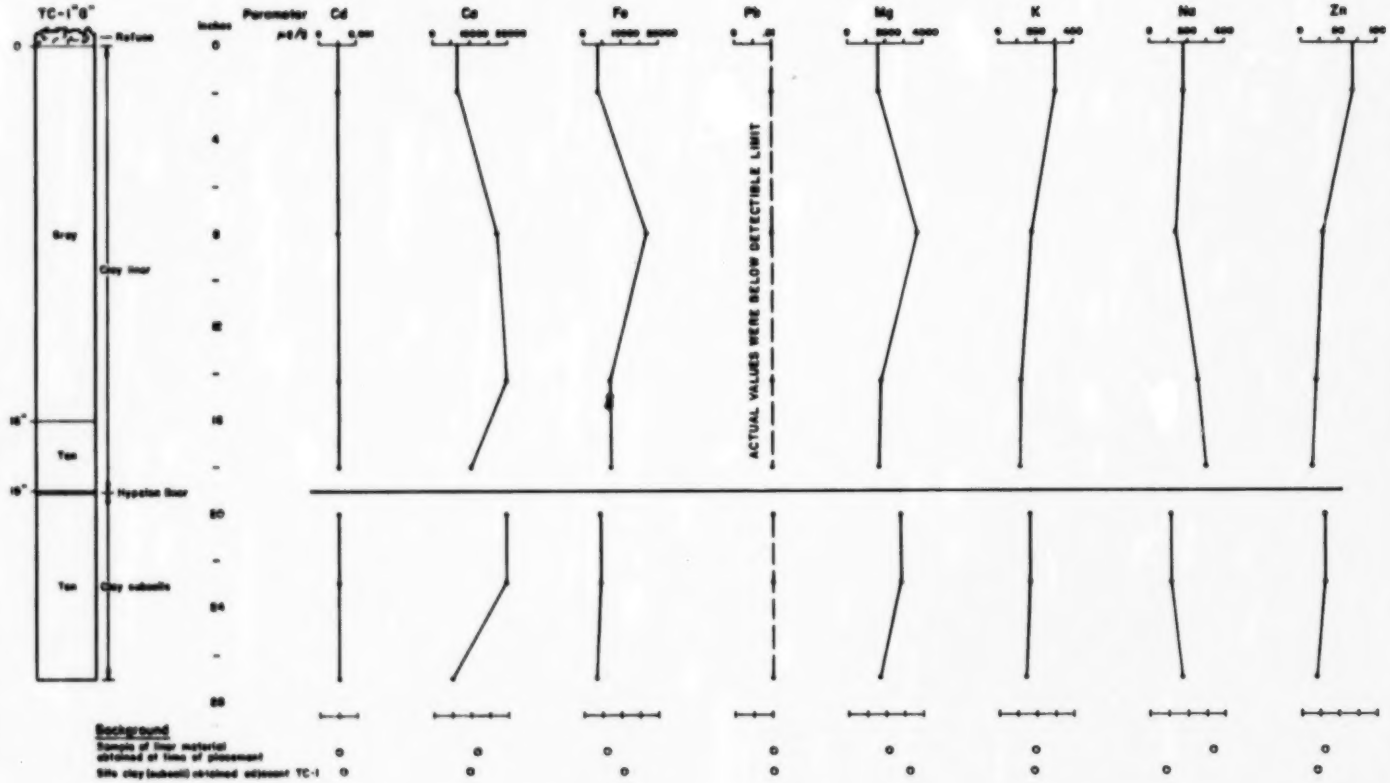


Figure 9. Chemical Analysis of Clay Liner - TC-1E.



Note: Acid extraction process used for soil testing.

Figure 10. Chemical Analysis of Clay Liner - TC-16.

Synthetic Liners--

Three CSPE samples and one LDPE sample were collected from TC-1. The CSPE samples were taken from the unreinforced 30-mil (0.76 mm) sheeting that had been centered on the base of the cell to prevent leachate migration below the cell (see Figure 3). The LDPE sample was taken from the unpigmented 6-mil (0.15 mm) LDPE liner of the trench installed in the top 7-1/2 in (19 cm) of the clay liner (Figure 3).

Tests showed that the amount of leachate that had penetrated the clay liner and contacted the CSPE liner was only a fraction of the actual quantity of leachate generated in the cell during the 9-year study period. Furthermore, this leachate was shown to be more dilute than that collected in the upper pipe. Nonetheless, the CSPE liner had been in contact with this small amount of dilute leachate for the full 9 years. The LDPE liner from the upper pipe had been in contact with full-strength leachate for the same period.

The leachate-exposed samples were sealed in polyethylene bags and kept damp until tested. Test results for all liner samples from TC-1 are summarized in Table 7.

CSPE Results. The CSPE samples exposed to leachate showed imprints of gravel and were swollen and soft. They had a small-scale rough appearance similar to that of a nervy compound after calendering. (Nerve in uncrosslinked polymer compounds is the unrelieved stress introduced during manufacture of the sheeting either by calendering or by extrusion.) Calender roll markings were not visible to indicate grain direction. Seams had blisters filled with a fluid that appeared to be essentially water.

Substantial amounts of the dilute leachate were absorbed by the CSPE samples; weights increased by 23.9% to 28.4%, and volumes increased by 57%, based on the original composition.

The ash values and the relatively high specific gravities reported in Table 7 indicate a high inorganic filler content. The extractables (after the volatiles were removed) are relatively low, indicating either a relatively low plasticizer content in the unexposed sheeting or a loss of plasticizer during exposure.

The physical properties of the CSPE samples all appear to be approximately the same. The thickness of the recovered samples was substantially higher than that of the original materials. Part of this increased thickness is due to the swelling, and part is probably a result of the relaxing of the compound and the puckering of the liner material (which occurred because of the residual nerve in the sheeting). The values all appear to be relatively normal for a CSPE material.

No significant differences were noted in the data among the different samples. This result indicates that the location of the sample in the cell did not affect the results, and that the materials all came from the same lot.

TABLE 7. PROPERTIES OF LEACHATE-EXPOSED CSPE AND LDPE SAMPLES FROM TC-1

Parameter	30-mil CSPE liner			6-mil LDPE liner
	Trench E No. 12	Trench B No. 14B	Trench G No. 16	Median No. 14B
Chemical analyses				
Volatiles, %[a]	28.2	28.4	22.9	...
Ash (db), %[b]	21.98	21.88	23.32	0.15
Specific gravity (db)[c]	1.457	1.440	1.442	...
Extractables, %[d]	2.97	3.77	3.07	1.10
Physical properties				
Thickness, as received	45.0	43.5	43.0	7.0
Thickness, devolatilized	45.9	46.6	44.6	6.6
Tensile set, ppi				
machine	...	...	...	9.9
transverse	...	...	...	9.9
Breaking factor, ppi				
machine	53.2	59.2	59.2	11.0
transverse	48.8	48.8	46.0	10.2
Elongation at break, %				
machine	300	300	310	345
transverse	350	320	370	225
Set after break, %				
machine	111	100	110	245
transverse	140	116	146	119
Stress at 100%, ppi				
machine	26.3	22.8	24.6	9.6
transverse	14.0	14.7	12.4	9.6
Stress at 200%, ppi				
machine	42.8	39.1	40.0	9.7
transverse	24.8	17.0	21.2	9.6
Tear strength, lb				
machine	6.5	6.6	6.8	2.9
transverse	6.7	6.1	6.5	2.8
Hardness (Duro A)				
instant reading	58	66	59	...
5-sec reading	54	60	56	...
Puncture strength				
stress, lb	33.3	35.3	33.9	7.0
elongation, in	0.90	0.91	0.86	0.37
thickness, mil	45.5	44.0	42.0	7.0

[a]Volatiles equal the accumulated weight loss on drying for 7 days in air at room temperature, 6 days in oven at 50°C, and 2 hr in air oven at 150°C.

[b]db = after devolatilization.

[c]Specific gravity of the specimen devolatilized in (a).

[d]Extractables of specimens after devolatilization. Solvent is n-heptane.

Changes in properties that occurred during exposure cannot be measured, since a sample of the CSPE sheeting was not retained and no baseline data are available on the original unexposed sheeting. However, two small samples of unreinforced CSPE sheeting manufactured in 1971 or 1972 were tested to obtain data on a comparable material. Test results are compared in Table 7 with those for three CSPE samples recovered from the test cell. Note, however, that CSPE liner compounds tend to crosslink with age and change their properties. Since the data show a relatively great divergence in properties, it is not possible to present retention data. But values for the leachate-exposed samples are between those for the two unexposed samples.

LDPE Results. The LDPE film was clear after the surface stain was washed off, and it appeared to be unaffected by its 9 years of exposure to the unattenuated leachate. The sample showed little swelling, and its properties (Table 8) were normal for a 6- to 7-mil (0.15 to 0.17 mm) LDPE. No punctures or tears of the material were observed during sample removal.

Subsoils

An excavation was made into a thin clay mantle overlying limestone bedrock in TC-1. When the cell had originally been excavated in 1970, fractured limestone was encountered in scattered locations. Wherever limestone was exposed at that time, 7 in (18 cm) of clay from the site was placed and compacted to a wet density of 126 lb/ft^3 (2,018 kg/m^3) at 24% moisture (dry-weight basis).

Clay subsoils were exposed at Locations B, E and G beneath the CSPE liner. The clay immediately below this liner was a brown-gray for several millimeters, grading to a natural orange-tan. This clay was similar in consistency to the clay liner in TC-1, with an average liquid limit of 40 and a plasticity index of 18. Soil testing data are summarized in Table 9, and a chemical analysis of the subsoils and their relationship to the overlying clay liner are presented in Figures 9 and 10.

TEST CELLS 2A, 2B AND 2C

Description

Test Cells 2A, 2B, and 2C consisted of refuse enclosed in identical cylindrical steel pipes 6.0 ft (1.83 m) in diameter and 12.0 ft (3.66 m) high. The pipes were placed vertically on reinforced concrete pads that had been constructed in an excavation (see Figure 11). The soil around the outside of the pipe was replaced to help support the pipe, as well as to moderate temperature fluctuations.

Refuse was placed in the pipes in approximately 200- to 300-lb (90- to 130-kg) increments. The program was specially designed to keep the refuse composition for all pipes as similar as possible. Each layer was compacted by dropping a 300-lb (130 kg) weight from approximately 4 ft (1.2 m) above the refuse until no further compaction was achieved.

TABLE 8. COMPARISON OF CSPE FROM TC-1 WITH TWO UNSUPPORTED CSPE SHEETINGS

Parameter	Average value for leachate-exposed CSPE	Value of Manufacturer A 30-mil liner		Value for Manufacturer B 30-mil liner aged in lab
		Unexposed	Aged in lab	
Chemical analyses				
Volatiles, %[a]	26.5	0.84	0.5[b]	0.3[b]
Ash (db), %[c]	22.4	33.5	39.9[b]	3.6[b]
Specific gravity	1.446(db)	1.433(ar)[d]	1.429(ar)	1.376(ar)
Extractables (db), %[e]				
Physical properties				
Thickness (ar)	43.8	31	31	31.2
Thickness (db)	45.7	...	...	...
Breaking factor, ppi				
machine	57.2	51.2	79.0	58.9
transverse	47.9	44.4	73.0	50.5
Elongation at break, %				
machine	305	575	500	300
transverse	345	645	525	310
Set after break, %				
machine	107	367	199	142
transverse	134	375	202	148
Stress at 100%, ppi				
machine	24.6	20.8	23.3	33.9
transverse	13.7	16.0	17.9	26.3
Stress at 200%, ppi				
machine	40.6	26.4	26.9	56.5
transverse	24.3	19.2	19.5	26.0
Tear strength, lb				
machine	6.6	8.8	9.8	9.7
transverse	6.4	8.3	8.0	9.4
Hardness (Duro A)				
instant reading	61	86	83	86
5-sec reading	57	83	83	85
Puncture resistance				
stress, lb	34.2	25.4	40.8	42.2
elongation, in	0.89	1.16	1.00	0.68
thickness, mil				

[a]Volatiles equal the weight loss after 2 hr at 105°C.

[b]Value obtained using thermogravimetric analysis.

[c]db = after devolatilization.

[d]ar = as received

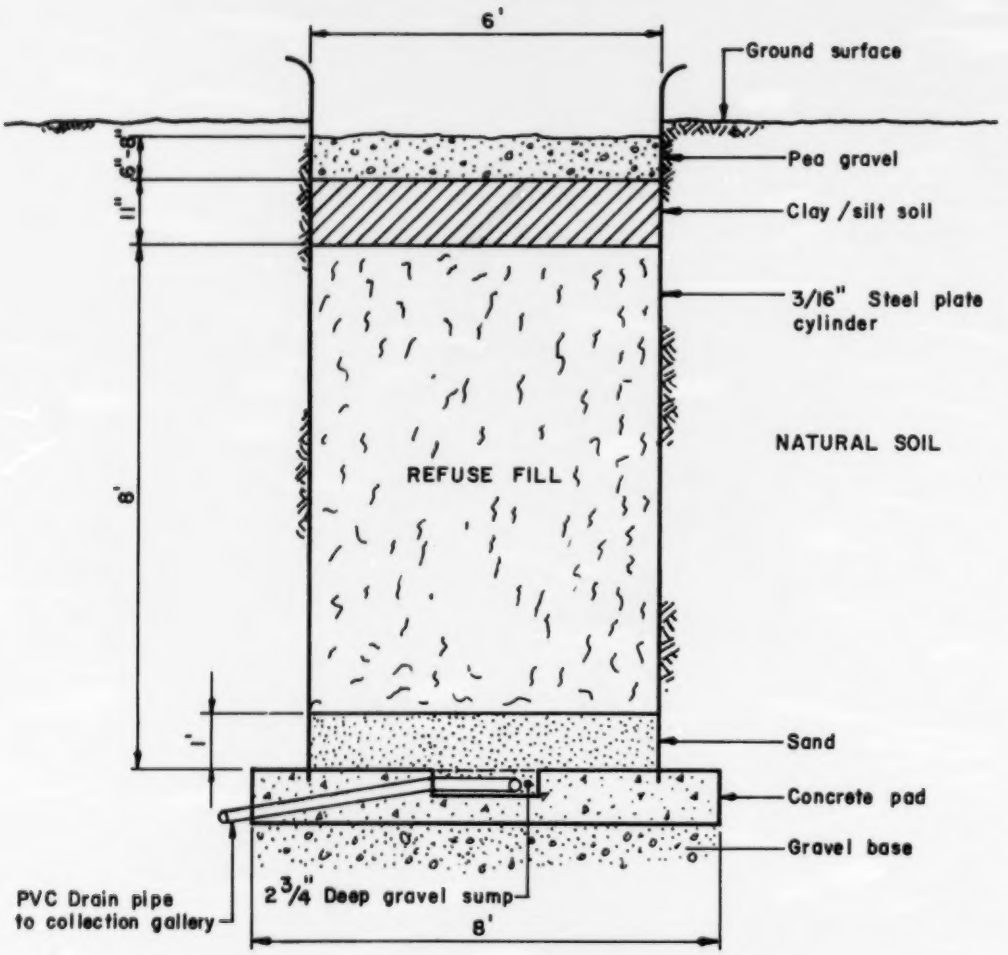
[e]Solvent is n-heptane for leachate-exposed CSPE sample, acetone for unexposed Manufacturer A liner.

TABLE 9. SOIL TESTING DATA FOR SUBSOILS FROM TC-1

	Location B[a]	Location G	Location E
Sieve analysis[b]			
clay, %	0	3	0
silt, %	92	94	93
sand, %	8	3	7
Liquid limit, %	31	41	48
Plasticity index, %	11	17	26
Unified soil classification	CL	CL	CL
Moisture content, %	27	22	28
Dry density, lb/ft^3	94	101	97
Permeability, cm/sec			
in-place	3×10^{-7}	6×10^{-7}	4×10^{-7}
laboratory	10×10^{-8}	3×10^{-8}	5×10^{-8}

[a]See Figure 3 for location of excavations.

[b]ASTM-ASCE grain size scale.



Not to scale

Figure 11. Test cell construction details for TC-2A, 2B, and 2C

Since construction of the three cells was similar, TC-2B was judged to be representative and was therefore excavated and examined in detail. The cover soil and shallow refuse in TC-2C were also investigated to confirm the assumed similarity. No study was made of TC-2A.

Test Cell 2B

Soil Cover--

Refuse in TC-2B was covered by a surficial layer of approximately 3/8-in-maximum-diameter (0.9 cm) clean pea gravel underlain by a light brown clay of low plasticity (CL) (Figure 11). The gravel layer, ranging in thickness from 6 to 8 in (15 to 20 cm), was placed to allow rapid percolation of rainfall and to minimize evaporation. The gravel was moist below the upper few inches. No vegetation was established in the gravel or underlying clay soil.

The clay layer was 11 in (28 cm) thick, becoming gray within 3 in (8 cm) of the refuse. The cover soil was very soft and moist to the touch.

Soil test data are summarized on Table 10. As tested in the laboratory, the permeability of a representative sample of cover soil was 2×10^{-7} cm/sec.

Refuse--

The physical appearance and composition of refuse in TC-2B after 9 years of exposure was similar to that of the other test cells. Newsprint was still quite legible (although slightly faded), cardboard was very soft with loss of structure, metal cans were slightly rusty, painted labels on metals were discolored but legible, and plastics were generally still pliable.

A strong odor was noticed once the clay cover was penetrated, but it quickly dissipated as refuse was removed from the cell. The refuse was very moist to the touch and wet on many surfaces. No free fluids were encountered anywhere in the refuse.

Chemical Analysis. Samples of refuse were obtained for chemical assay to determine vertical differentials in composition. The results did not present clearly defined trends for most assays. Potassium did exhibit a weak trend of decreasing concentration with increasing depth. This trend is contrary to that expected from single-pass, one-directional leaching reactors. It is not considered significant because it is the only such trend and the range over which it occurs is small, possibly resulting from sampling and analytical precision and accuracy.

Pore Water. Samples of refuse were obtained 2, 5 and 6.5 ft (0.6, 1.5 and 2 m) below the test cell surface, and water was extracted from these samples. Results from TC-2B are generally consistent in that apparent trends contradict the results of all other test cells. This finding is not considered significant; however, errors in sampling and analytical procedures may account for the results obtained.

TABLE 10. SOIL TESTING DATA FOR TC-2B AND TC-2C

	TC-2B cover soil	TC-2C cover soil	TC-2B sand collector	TC-2B gravel collector
Sieve analysis[a]				
clay, %	0	0	0	0
silt, %	95	82	0	1
sand, %	5	18	100	17 (83% gravel)
Liquid limit, %	38	41	...	...
Plasticity index, %	16	19	...	...
Unified soil classification	CL	CL	...	...
Moisture content, %	25	27	...	...
Dry density, lb/ft^3	100	93	...	...
Permeability, cm/sec				
in-place	...	5×10^{-6}	...	...
laboratory	2×10^{-7}	7×10^{-7}	...	...

[a]ASTM-ASCE grain size scale.

A comparison of contaminants in pore water and in leachate indicate higher concentrations in the leachate, except for total solids, total volatile solids, TKN, Zn, As and Ba. The results for TC-2B are thus unique when compared with those of the other test cells.

Leachate Collection System--

The refuse is underlain by a sand and gravel leachate collection system (Figure 11). The sand was classified as medium-sized (see Figure 12) and was light tan throughout its thickness. Comparison of the sand tested with a record sample of sand indicates that fines have been washed from the sand. No signs of leachate precipitates or discoloration were observed. Similar conditions were observed for the gravel surrounding the system drain pipe (see Figure 11).

Inspection of the fiberglass seal between the steel walls and the concrete floor indicated a generally good connection. No deterioration of the fiberglass or epoxy was noted.

Test Cell 2C

Soil Cover--

The soil cover in TC-2C, composed of a 6- to 8-in-thick (15- to 20-cm-thick) layer of loose pea gravel overlying approximately 1 ft (30 cm) of compacted silty soil, is similar to that in TC-2B. The soil layer was brown, becoming gray within 5 in (13 cm) of the refuse. The cover soil was soft and moist to the touch. Permeability of the soil cover, tested both in situ and in the laboratory, was found to be 5×10^{-6} cm/sec in situ and 7×10^{-7} cm/sec in the laboratory. Soil testing data are summarized on Table 10.

Refuse--

No excavation was made into the refuse in TC-2C, due to its similarity to TC-2B.

TEST CELL 2D

Description

Test Cell 2D was constructed in an excavation approximately 28 ft^2 (2.6 m^2) and 10 ft (3 m) deep, to provide a large-scale comparison for the three smaller test cells (TC-2A, 2B, and 2C) that were constructed concurrently. The base of the cell was shaped with sand and a 0.30-in-thick (7.6-mm-thick), unreinforced chlorinated polyethylene (CPE) liner was placed along the cell sidewalls and over the base. Plywood sheets were placed against the synthetic liner on the sidewalls for protection during cell filling, and a sand blanket was placed on the lining base of the cell to facilitate leachate movement to a central drain. Construction details are illustrated in Figure 13.

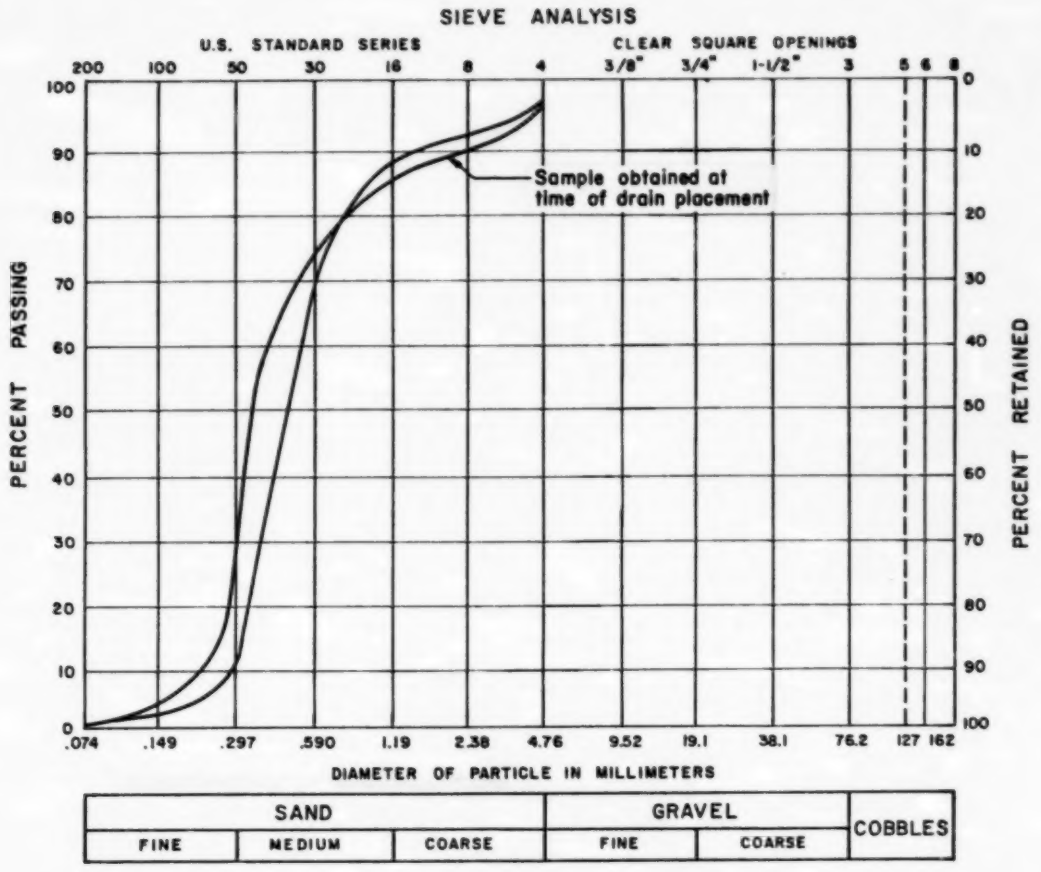

SIEVE ANALYSIS
U.S. STANDARD SERIES
CLEAR SQUARE OPENINGS
200 100 50 30 16 8 4 3/8" 3/4" 1-1/2" 3 5 6 8
PERCENT PASSING
PERCENT RETAINED
100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100
Sample obtained at time of drain placement
.074 .149 .297 .590 1.19 2.38 4.76 9.52 19.1 38.1 76.2 127 162
DIAMETER OF PARTICLE IN MILLIMETERS
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
COBBLES

Figure 12. Grain size analysis for collector sand in TC-2B.

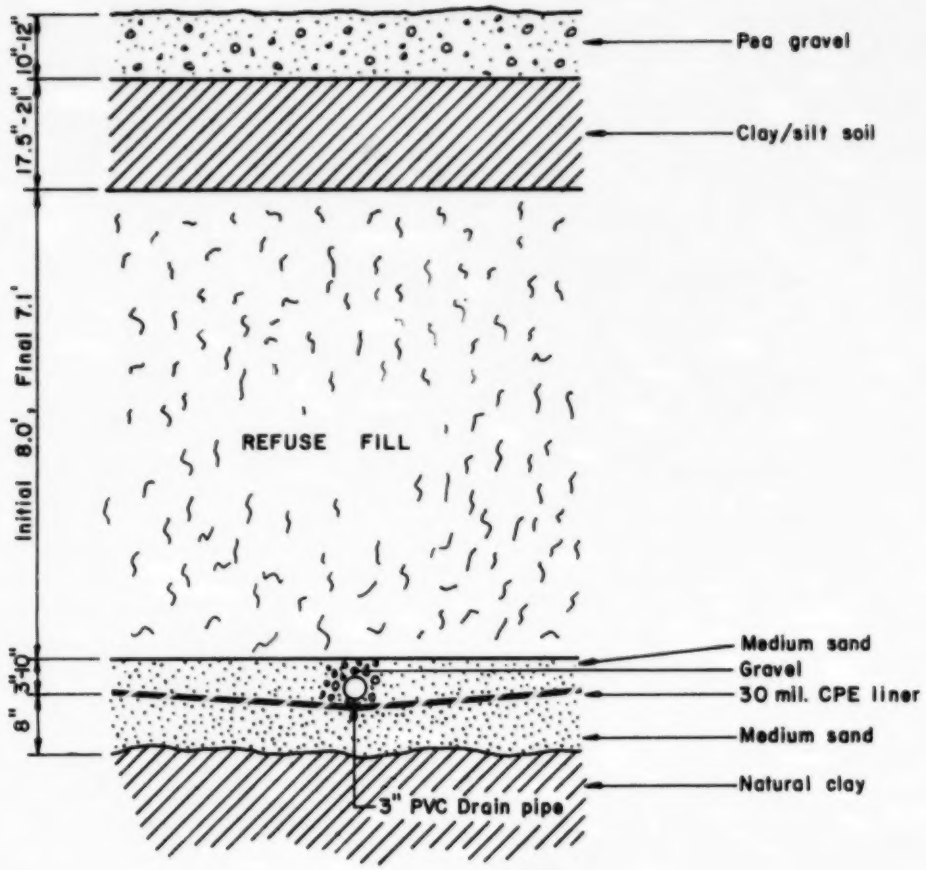


Figure 13. Test cell construction details for TC-2D.

A Case 450 bulldozer was lowered into the cell by a crane. Refuse was then added by the crane from a stockpile and compacted by the bulldozer.

TC-2D was explored by three excavations that penetrated through the cell into the underlying subsoils (see Figure 14).

Cover Soil

TC-2D is capped by a surficial layer of clean pea gravel overlying a clay cover soil (Figure 13). The gravel, ranging in thickness from 10 to 12 in (25 to 30 cm), was placed to allow rapid percolation of rainfall and to minimize evaporation. The gravel was dry near the surface, but very moist below the upper 3 to 4 in (8 to 10 cm). No vegetation was established in the gravel.

The gravel covered a berm system installed to promote uniform modular percolation of rainfall into the refuse cell. The system consisted of approximately 5-in-high (13-cm-high) triangular-shaped clay berms that were hand constructed on top of the soil cover (Figure 15). Excavation showed the berms to be intact, with a good bond to the top of the cover soil. Penetration of gravel into the clay cover soil was very limited, generally less than 1 in (2.5 cm).

The cover soil, classified as a clay of low plasticity (CL) by the Uniform Soil Classification System, was orange-tan sandy clay with occasional shale rock fragments. The lower 3 in (9 cm) of the soil cover was altered in places to a gray color from its natural orange-tan. The average liquid limit was 42%, and the average plasticity index 18%. Clay content ranged from 0% to 28% by dry weight. A summary of soil testing data is presented in Table 11.

Cover soil thickness ranged from 17.5 to 21.0 in (44.5 to 55.3 cm). The clay was easily excavated by shovel and felt moist to the touch, unlike the dry, hard texture of the cover soil in TC-1. No signs of fracturing or channeling were observed, and the presence of surficial gravel prevented development of a root or weathered zone.

The permeability of the cover soil was investigated by both field and laboratory methods (see Appendix A). Permeabilities were found to be approximately one order of magnitude smaller than in TC-1, reflecting an increased clay content and greater plasticity. Permeability values ranged from 3×10^{-2} to 6×10^{-6} cm/sec for in-field tests and 1×10^{-7} to 3×10^{-8} cm/sec for laboratory tests. As in TC-1, the field permeability value were greater than those of the laboratory determinations: for TC-1 they were 52 times greater, and for TC-2D they were 70 times greater.

Refuse

Three trenches were dug to expose a cross section of the refuse pile in TC-2D (A, B, and C, See Figure 14). Upon removal of the cover soil, zones of wet refuse were observed in the upper 2 to 3 ft (61 to 91 cm) of refuse. The refuse was more odorous than in TC-1, and it had a higher moisture content throughout its thickness -- 49% to 65% on a wet-weight basis (see Table 12).

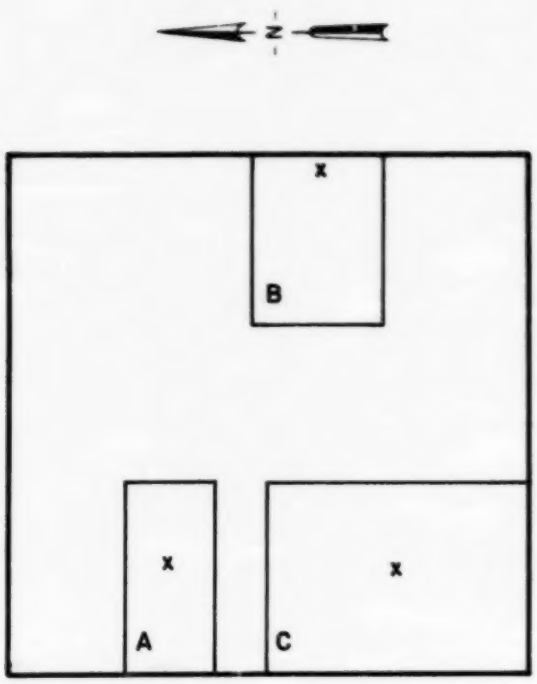
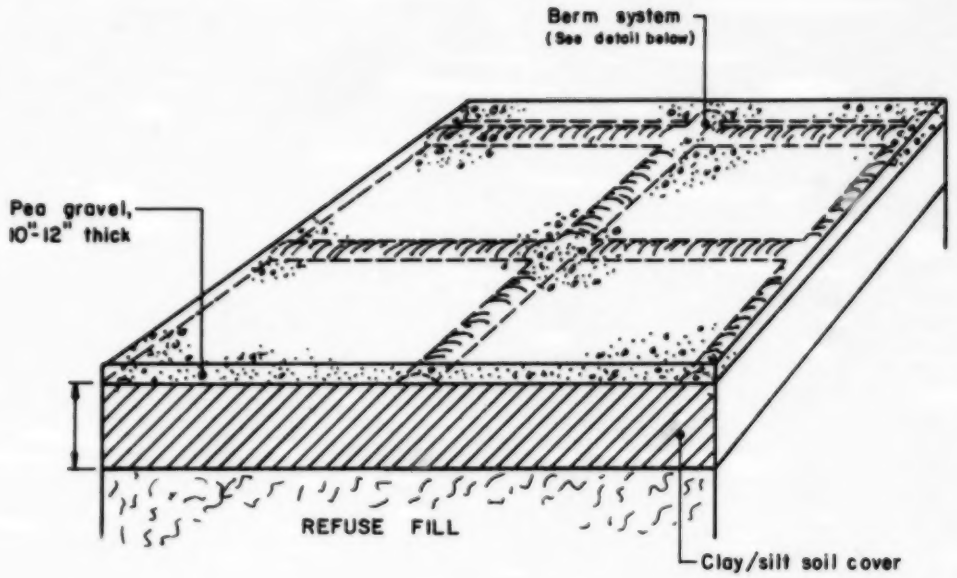
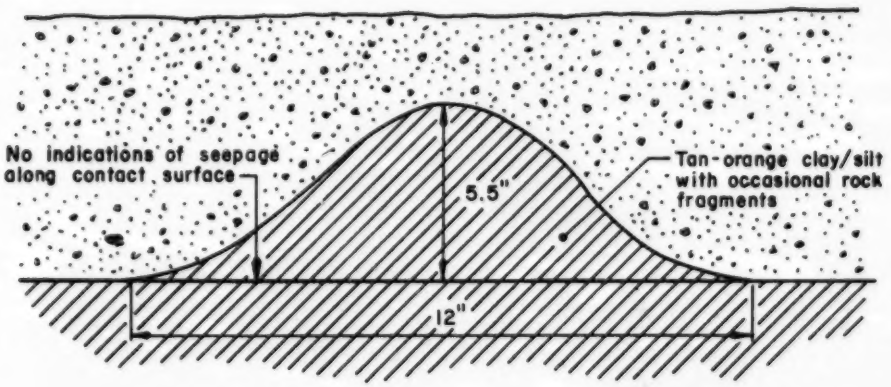


Figure 14. Sampling locations for TC - 2D.





BERM DETAIL

Figure 15. Cover soil and berm details for TC-2D.

TABLE 11. SOIL TESTING DATA FOR COVER SOIL IN TC-2D

	Location A[a]	Location B	Location C
Sieve analysis[b]			
clay, %	28	0	23
silt, %	66	77	65
sand, %	6	23	12
Liquid limit, %	42	38	42
Plasticity index, %	19	16	20
Unified soil classification	CL	ML-CL	CL
Moisture content, %	29	27	28
Dry density, lb/ft^3	94	92	90
Permeability, cm/sec			
in-place	5×10^{-6}	6×10^{-6}	3×10^{-6}
laboratory	3×10^{-8}	10×10^{-8}	7×10^{-8}

[a]See Figure 3 for location of excavations.

[b]ASTM-ASCE grain size analysis.

TABLE 12. REFUSE TEST DATA FOR TC-2D

Cell location	Depth[a] (ft)	Depth[a] (m)	Moisture content[b] (%)	Refuse density: Dry density (lb/yd^3)	Refuse density: Dry density (kg/m^3)	Refuse density: Wet density (lb/yd^3)	Refuse density: Wet density (kg/m^3)	Refuse Permeability (cm/sec)
A	4	1.2	60	1296	769	2080	1234	3×10^{-2}
A	6	1.8	52	1579	937	2180	1293	2×10^{-1}
A	8	2.4	52	1360	807	2067	1226	6×10^{-2}
B	4	1.2	63	922	547	1510	896	2×10^{-2}
B	6	1.8	62	1890	1121	3057	1813	2×10^{-2}
B	8	2.4	65	1137	674	1874	1112	3×10^{-2}
C	4	1.2	58	1138	675	1798	1066	1×10^{-2}
C	6	1.8	49	1800	1068	2688	1595	2×10^{-2}
C	8	2.4	65	1749	1037	2886	1712	9×10^{-2}
Mean	...	...	58	1430	848	2237	1327	5×10^{-2}

[a]Measured from surface of landfill cover system.

[b]Expressed as wet weight: (weight of water)/(weight of water + solids).

As in TC-1, the degree of refuse degradation was low. Newsprint was very legible, cardboard structure was still intact, metals had little rust or corrosion, labels on metal cans were only slightly discolored, grass clippings were bright green, and plastics were still pliable. Again, as with the other test cells, food waste was not observed except for isolated bones, corncobs and similar materials.

Chemical Analysis--

Analyses of samples taken at two locations in TC-2D generally showed a trend of decreasing concentrations with increasing depth. The same trend was found for SO_4, Na, K and Mg. Other constituents assayed showed no trends. Since the ranges in the trends noted are less than one order of magnitude, they are considered weak. Although these findings do not support the concepts generally associated with single-pass systems, it may be that the mode of operation of these test cells led to the results obtained. Leachate was often stored within the refuse, which may have influenced the dissolution of chemicals.

Pore Water--

Concentrations of most contaminants were greater in pore water than in leachate. Such was not the case for Fe, however, and Cl, K, and Ca concentrations were approximately equal in the two samples. Contaminant concentrations generally increased with depth, but Ca and Fe are noted exceptions to this trend. For samples taken at Location 2-DA, TOC, COD and Zn also are exceptions. Again, sampling errors should be considered before drawing conclusions about these exceptions.

Moisture Content--

The refuse pile was generally well drained, and no zones of perched fluids were encountered. Trenches remained dry until saturated drain soils were exposed.

Density--

The in-place density of the refuse was estimated at nine points within the refuse by the test method described in Appendix A. The mean wet refuse density was determined to be 2,237 lb/yd^3 (1,327 kg/m^3); the mean dry density, 1,430 lb/yd^3 (848 kg/m^3) (see Table 12).

Permeability--

The in-place permeability of refuse was estimated at nine locations, using the field test methods described in Appendix A. The mean permeability was determined in the field as 5×10^{-2} cm/sec. This value should be regarded as somewhat high because it was not possible to completely seal the permeameters within the refuse. Permeability test results, summarized in Table 12, are comparable with those found in TC-1.

Drainage Soil

In TC-2D, the refuse was separated from an underlying chlorinated polyethylene (CPE) liner by a sand collector blanket. A slotted PVC pipe was placed along the transverse center line of the cell for leachate collection and gravity drainage to the adjacent collection well. Silica gravel was then placed on the top and sides of the collection pipe (see Figure 13).

The sand blanket exposed in the three trenches (A, B and C) was light tan and remarkably similar in texture and color to samples retained from the time of placement. The sand blanket ranged in thickness from 3 to 10 in (8 to 25 cm), averaging approximately 8 in (20 cm). Laboratory sieve analysis classified most of the sand as medium-sized (0.3 to 1.2 mm). The sand had collected 3% to 4% silt and clay over the original clean material. Representative gradation curves are shown on Figure 12.

The sand was very moist to wet. The lower several inches of the sand blanket were typically saturated and black in scattered areas. In some locations, the black staining was associated with a thin 1-in (2.5-cm) layer at the refuse contact; in others, the staining was gradational, increasing in darkness downward toward the liner contact.

The central gravel drain was exposed in Trenches A and B. In Trench A, 3 in (8 cm) of tan sand was found overlying 4 in (10 cm) of gravel on top of the slotted PVC drain. The PVC pipe was underlain by 1 in (2.5 cm) of gravel, which overlay the CPE liner. The gravel extended outward approximately 18 in (46 cm) from the center line of the pipe and was tightly packed in fine to medium sand. Individual gravels around the PVC pipe were stained with rust and fine black material. The sand matrix was generally gray, grading to black adjacent to and below the pipe.

The drain system was moist, but no free fluids were encountered in Trench B and only a very slow seepage in Trench A. Slots in the PVC pipe were open.

Laboratory sieve analysis revealed that the gravel was composed primarily (>70%) of clasts ranging from 1.5 to 2 in (4 to 5 cm) long. Samples of drain material contained an average of 15% sand and less than 2% clay and silt-sized material.

Liner

Six samples were taken of the 30-mil (0.76-mm) unreinforced CPE liner in TC-2D. Four of the samples were taken from the bottom of the cell, and two were collected above ground at the top of the cell (the latter samples had thus been exposed to the weather, but not to leachate). Figure 13 shows the position of the CPE liner in relation to the other construction details of TC-2D.

Leachate-Exposed Samples--

Analyses. The four samples from the bottom of the cell had been exposed to all the unattenuated leachate generated within the cell during the 9 years of operation. Chemical analyses of the layers of sand above and below the CPE liner indicated that leachate had been contained within the cell. The composition of this leachate is described by Wigh and Brunner.* Properties of the leachate-exposed liner samples are presented in Table 13.

The samples were stiff and leathery. The fine parallel line pattern introduced during calendering was visible on the surface and could be used to indicate grain direction. Also visible was a fine diamond-shaped pattern on the reverse side of the sheeting.

Though the exposed CPE samples showed significant adsorption of leachate, their properties were relatively good. Volatile contents ranged from 16.7% to 18.8%; the latter value is equal to an increase of 23% by weight (based on the original), or a 31.7% increase by volume.

The data on the volatiles and on the devolatilized samples indicate that two different compositions are involved. The A and C samples are one composition, and the B samples are another. The two B samples have somewhat lower ash contents, volatiles, and extractables. Differences are also apparent in the results of the physical property tests.

Since most of the samples were swollen, the volatiles had to be removed slowly to avoid a blistering or bubbling of the compound (such as would occur with wet samples that were being dried at too high a temperature). The highly swollen specimens were first dried to approximately constant weight at room temperature (about one week). They were then heated at 50°C for several days to reach constant weight, and finally at 105°C for 2 hr to remove all water. With more rapid removal of volatiles, bubbles formed in the polymer layer and the sample could not be used for a specific gravity determination. The test specimen was a 2-in (50-mm) disk that was dried from the wet liner sample. Heating it at 105°C caused the sample to relax and shrink in the grain direction.

Specific gravity was measured, and ash content and extractables determined, after the volatiles were removed by the procedure described above. The ash reflects the inorganic filler content of the original liner compound. Extractables of the devolatilized sample can be either greater or less than those in the original compound, depending on whether the sample has absorbed nonvolatile organic constituents from the leachate, or whether the original compound has lost plasticizer to the leachate.

*Wigh, R. J., and D. R. Bruner, Summary of Landfill Research - Boone County Field Site, In: Proceedings of the Seventh Annual Research Symposium at Philadelphia, PA, EPA-600/9-81-002a, 1981, U.S. Environmental Protection Agency, Cincinnati, Ohio, pp. 209-242, 1981.

TABLE 13. PROPERTIES OF LEACHATE-EXPOSED AND WEATHERED CPE FROM TC-2D

Parameter	Excavation trench and sample number					
	TC-2DA No. 11	TC-2DC No. 13	TC-2DB No.15A	TC-2DB No.15B	TC-2DWA No. 20	TC-2DWB No. 21
Chemical analyses						
Volatiles, %[a]	18.8	18.3	17.6	16.7	6.63	7.25
Ash (db), %[b]	13.36	13.31	13.02	13.03	13.21	15.20
Specific gravity (db)[a]	1.372	1.376	1.368	1.361	1.34	1.34
Extractables, %[c]	4.81	4.42	4.43	5.15	4.42	3.81
Physical properties						
Thickness, as received	41.5	40.0	37.0	39.0	34	34
Thickness, devolatilized	39.2	39.4	35.1	38.9	...	...
Breaking factor, ppi						
machine	55.6	58.8	52.8	54.0	73.0	78.4
transverse	44.0	46.8	39.6	42.4	55.6	60.3
Elongation at break, %						
machine	240	220	270	260	275	295
transverse	320	310	335	350	335	335
Tensile set, %						
machine	134	117	147	131	178	187
transverse	125	115	136	123	168	157
Stress at 100%, ppi						
machine	36.1	41.6	30.5	33.6	49.5	54.7
transverse	17.7	18.3	14.6	14.1	24.9	32.1
Stress at 200%, ppi						
machine	51.2	57.6	43.6	46.8	62.2	66.0
transverse	28.3	30.2	23.9	22.9	36.0	42.5
Tear strength, lb						
machine	8.7	7.7	7.0	7.8	8.1	9.5
transverse	6.0	6.4	6.4	6.9	6.3	7.0
Hardness (Duro A)						
instant reading	79	78	65	69	77	72
5-sec reading	67	69	60	59	71	69
Puncture strength						
stress, lb	36.6	41.2	36.4	37.8	46.6	48.8
elongation, in	0.78	0.77	0.80	0.83	0.68	0.79
thickness, mil	39.0	40.0	37.0	40.5	34	34
Seam strength						
shear, lb	...	...	...	...	26.8	42.9
locus of failure[d]					AD	BRK/SE
peel - max/avg, lb	...	...	...	...	4.1/3.5	4.4/4.0
locus of failure[d]					AD	AD

[a]Data obtained on the CPE exposed to weather in field. No leachate exposure.

[b]db = after devolatilization.

[c]Extractables of specimens after devolatilization. Solvent is n-heptane.

[d]Locus of failure codes: AD = failure in adhesion; BRK = break of liner material outside seam area; SE = failure at seam edge.

Physical Properties. The effect of leachate exposure on the liner material was also measured by changes in physical properties resulting from exposure. Tensile properties, tear resistance, hardness, and puncture resistance were all tested (Table 13).

Tensile properties were measured in accordance with ASTM D 412, modified. Dumbell specimens with cross sections of 0.25 in (6.4 mm) were used, and the jaw separation speed was 20 in/min (500 mm/min). The values reported were: (1) breaking factor, (which is the tensile of a 1-in (25.4-mm) width), (2) elongation at break in percent, (3) tensile set after break, in percent, and (4) stresses at 100% and 200% in pounds per inch width.

Tear resistance was measured according to ASTM D 624 using an unnicked 90° angle specimen (Die C) and a jaw separation rate of 20 in/min (500 mm/min).

Durometer hardness was measured according to ASTM D 2240. The puncture resistance was measured according to Federal Test Method Standard FTMS 101-2065.

Weathered Samples--

The two samples of CPE liner collected above the ground, where the liner extended beyond the cell, had been exposed only to the weather and not to leachate. These samples were significantly higher in tensile strength, moduli, and puncture resistance than the leachate-exposed samples (Table 14). The lower values for the latter samples probably reflect the swelling caused by leachate, but crosslinking during exposure may contribute to the higher values of the weathered samples.

Comparison of CPE Samples with Similar Unexposed Liners--

As in the case of the CSPE and LDPE liners, no comparisons could be made with the original sheetings because no material samples or data from the originals were available. However, a CPE material of the same style had been used in earlier EPA liner studies, and the original data for this liner (Matrecon Liner No. 12) could be used as a baseline. Average data for the CPE samples from TC-2D are therefore compared with the original Matrecon data in Table 15.

Compared with Liner 12, the weathered materials tended to increase in modules, and those exposed to leachate tended to drop. The tensile strengths of the weathered materials were slightly less than those of Liner No. 12; those of the leachate-exposed materials were significantly less.

Subsoils

An excavation was made into a layer of sand and a section of clay underlying the CPE liner in TC-2D (see Figure 16). Exploratory trenches had found the CPE liner to be under an upward hydrostatic pressure from fluids in the underlying sand. In Trench B, a bubble 8 to 10 inches in diameter (the width of the excavation) formed as refuse and the sand blanket were removed. Maxi-

TABLE 14. COMPARISON OF LEACHATE-EXPOSED AND WEATHERED CPE FROM TC-2D

Parameter	Average value for weathered sample	Average value for leachate-exposed sample
Chemical analyses		
Volatiles, %	6.94	17.9
Ash (db), %[a]	14.21	13.18
Specific gravity	1.34(ar)[b]	1.369(db)
Extractables, %[c]	4.12	4.60
Physical properties		
Actual thickness, mil	34	39 (+5)[d]
Breaking factor, ppi		
machine	75.7	55.3 (73)
transverse	58.0	43.2 (74)
Elongation at break, %		
machine	285	250 (88)
transverse	335	330 (99)
Tensile set, %		
machine	183	132 (72)
transverse	163	125 (76)
Stress at 100%, ppi		
machine	52.1	35.5 (68)
transverse	28.5	16.2 (57)
Stress at 200%, ppi		
machine	64.1	49.8 (78)
transverse	39.3	26.3 (67)
Tear strength (Die C), lb		
machine	8.8	7.8 (89)
transverse	6.7	6.4 (96)
Hardness (Duro A)		
instant reading	75	73 (-2)
5-sec reading	70	64 (-6)
Puncture resistance		
stress, lb	47.6	38.0 (80)
elongation, in	0.74	0.80 (108)
thickness, mil	34	39 (+5)

[a]db = after devolatilization.

[b]ar = as received.

[c]Solvent is n-heptane.

[d]Numbers in parentheses are the average value for leachate-exposed samples divided by the average value for the weathered samples multiplied by 100, except in the case of the hardness and thickness values, where the numbers in parentheses are the change in scale.

TABLE 15. COMPARISON OF CPE IN TC-2D WITH MATRECON LINER NO. 12

Parameter	Matrecon liner No. 12[a]	Average value for weathered CPE liner	Average value for leachate-exposed CPE
Chemical analyses			
Volatiles, %	0.10	6.94	17.9
Ash (db), %[b]	14.40	14.21	13.18
Specific gravity	1.360(ar)[c]	1.34(ar)	1.369(db)
Extractables, %[d]			
Physical properties			
Thickness as received, mil	31	(+3)[e]	(+8)
Breaking factor, ppi			
machine	77.6	(98)	(71)
transverse	65.6	(88)	(66)
Elongation at break, %			
machine	305	(93)	(82)
transverse	515	(65)	(64)
Tensile set, %			
machine	199	(92)	(66)
transverse	231	(71)	(54)
Stress at 100%, ppi			
machine	38.4	(136)	(92)
transverse	16.4	(174)	(99)
Stress at 200%, ppi			
machine	57.2	(112)	(87)
transverse	26.4	(149)	(100)
Tear strength (Die C), lb			
machine	8.4	(105)	(93)
transverse	7.3	(92)	(88)
Hardness (Duro A)			
instant reading	85	(-10)	(-12)
5-sec reading	77	(-7)	(-13)
Puncture resistance			
stress, lb	47.0	(101)	(81)
elongation, in	1.04	(71)	(77)
thickness, mil	32	(+2)	(+7)

[a]Haxo, H.E., R.M. White. Second Interim Report, Evaluation of Liner Materials Exposed to Leachate, EPA-600-2-76-255, U.S. EPA, Cincinnati, Ohio, Sept. 76.

[b]db = after devolatilization.

[c]ar = as received.

[d]Solvent is n-heptane.

[e]Figures in parentheses are precent retentions calculated using the values reported for Matrecon Liner No. 12 as 100%, except for hardness and thickness, where the figures in parentheses are the change in scale.

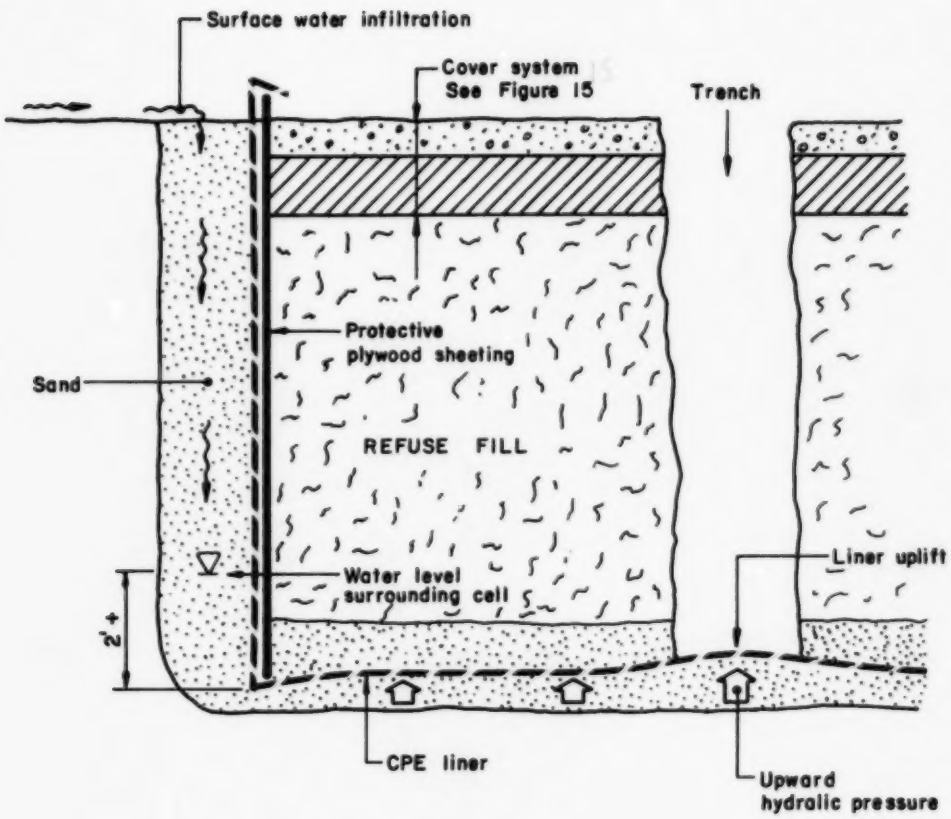


Figure 16. Liner uplift details for TC-2D.

mum vertical relief across the deformation was 5.5 in (13.8 cm). Similar but less well developed uplifts were observed in Trenches A and C.

Water from beneath the CPE liner was sampled in Trench B. Analysis of the samples (Table 15) indicated that the water did not contain leachate, confirming the integrity of the liner. The water had a chloride concentration of 25 mg/l and a COD concentration of 44 mg/l, compared with typical values of 500 and >20,000 mg/l, respectively, in leachate from TC-2D. Analytical test results of water from beneath the liner are presented in Table 16.

TABLE 16. ANALYSIS OF WATER UNDER TC-2D LINER[a]

Parameter	Test 1	Test 2	Average
Acidity, mg/l	16.65	...	16.65
Total volatile solids, mg/l	124	...	124
Chloride, mg/l	22.8	27.5	25.2
Chemical oxygen demand, mg/l	44.15	...	44.15
Iron, mg/l	20.3	...	20.3

[a]Standard addition data:

Slope	Intercept
0.940	21.5
0.931	25.6

The source of the water beneath the liner is believed to be the surface runoff into the sand surrounding the sides of the cell. Several feet of water were found trapped in the sand blanket outside the CPE liner (Figure 14).

Sand beneath the CPE liner was approximately 8 in (20 cm) thick. Laboratory tests showed it to be nearly identical in grain size to that above the liner. The sand was a light tan except for a 1/2- to 3/4-in (1.5 to 2 cm) gray zone at the point of contact with the CPE liner. Figure 17 presents the results of a grain size analysis of the sand blanket. Chemical analyses of collector sand and subsoils are depicted in Figure 18.

The sand supporting the liner was underlain by a thick section of natural clay of moderate to high plasticity, classified as CL-CH by the Unified Soil Classification System (Table 11). The upper 1 to 2 in (2.5 to 5 cm) of the clay had been reduced to a mottled gray-green, with the remainder of the exposed clay a natural orange-tan. Soil test data are summarized in Table 17.

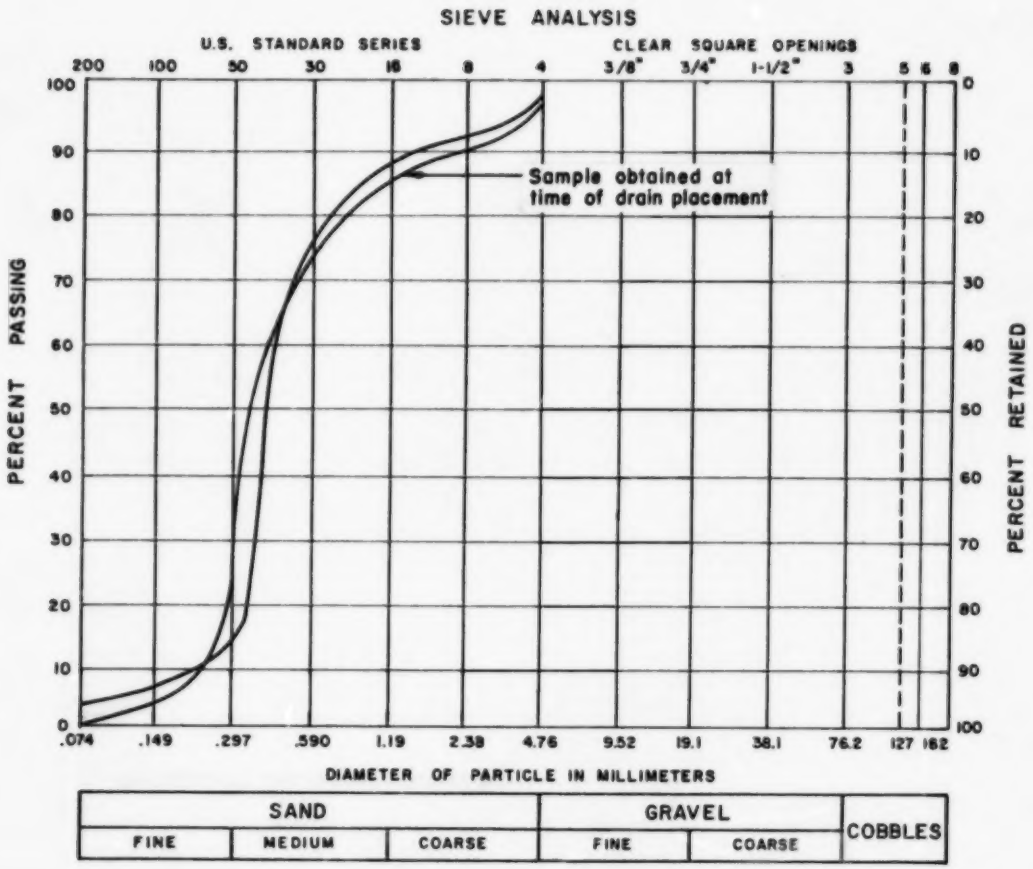


Figure 17. Grain size analysis for sand blanket in TC-2D.

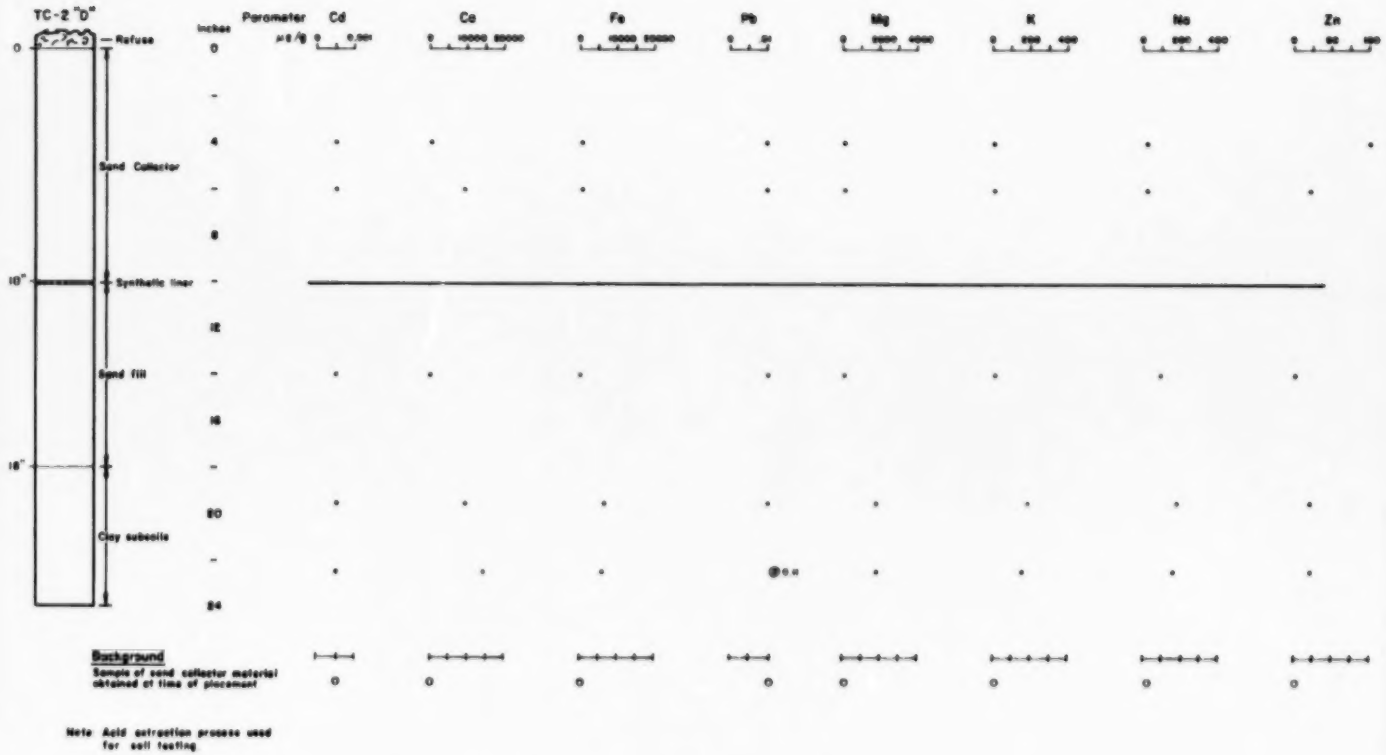


Figure 18. Chemical Analysis of Collector and Subsoils - TC-2b.

TABLE 17. SOIL TESTING DATA FOR SUBSOILS IN TC-2D

	Location A[a]	Location B	Location C
Sieve analysis[b]			
clay, %	49	44	46
silt, %	43	37	48
sand, %	8	19	6
Liquid limit, %	41	51	55
Plasticity index, %	19	27	29
Unified soil classification	CL	CH	CH
Moisture content, %	36	37	32
Dry density, lb/ft^3	82	87	88
Permeability, cm/sec			
in-place	1×10^{-7}	4×10^{-7}	5×10^{-7}
laboratory	2×10^{-8}	2×10^{-8}	6×10^{-8}

[a]See Figure 3 for location of excavations.

[b]ASTM-ASCE grain size scale.

REFERENCES

1. U.S. Environmental Protection Agency, Office of Research and Monitoring, Disposal Technology Branch, Cincinnati, Ohio. Interim Report 1, Test Cell 1, Boone County Field Site. Unpublished. 181 p. March 1973

2. Wigh, Richard J. Boone County Field Site Interim Report; Test Cells 2A, 2B, 2C, and 2D. EPA-600/2-79-058. U.S. Environmental Protection Agency, Cincinnati, Ohio. 192 p.

3. Wigh, Richard J., and Dirk R. Brunner. Summary of Landfill Research -- Boone County Field Site. In: Proceedings of the Seventh Annual Research Symposium at Philadelphia, PA, EPA-600/9-81-002a. 1981. U.S. Environmental Protection Agency, Cincinnati, Ohio. pp. 209-242. 1981.

4. American Public Health Association. Standard Methods for the Examination of Water and Wastewater, 14th ed. American Public Health Association, New York, New York. 1193 pp. 1976.

5. Dudley, D. J., M. N. Guentzel, M. J. Ibarra, B. E. Moore, and B. P. Sagik. Enumeration of Potentially Pathogenic Bacteria from Sewage Sludges. Appl. Environ. Microbiol., 39, 118-1216. 1980.

6. Geldreich, E. E. Fecal Coliform and Fecal Streptococcus Density Relationships in Waste Discharges and Receiving Waters. Crit. Rev. Environ. Control, 6, 349-369. 1976.

7. Donnelly, J. A., P. V. Scarpino, and D. Brunner. The Characterization of Microbes from Sanitary Landfills. In: Abstracts of the Annual Meeting 1980, American Society for Microbiology, p. 215. 1980.

Appendix A

PROCEDURES USED IN PHYSICAL TESTING OF SOIL/REFUSE SAMPLES

LABORATORY DETERMINATION OF HYDRAULIC CONDUCTIVITY

The saturated permeability or hydraulic conductivity of a soil sample can be measured with two types of laboratory apparatus: constant and falling head permeameters.

Samples for this study were tested under falling head conditions. This methodology is best suited for soils with moderate to low permeability, such as those in the Boone County test cells.

This method involves placing a soil sample in a triaxial apparatus and subjecting it to a confining pressure of 100 psi and an internal pressure (or pore pressure) of 95 psi to ensure complete saturation. A hydraulic gradient is produced across the sample with water flowing through it at heads of up to 48 in. Figure A-1 diagrams a typical laboratory permeameter that uses air pressure to create internal hydraulic gradients. The hydraulic conductivity is calculated from the basic equation:

$$K = \frac{aL}{At} \ln \left(\frac{H_o}{H_1}\right)$$

where

a = cross-sectional area of stand-pipe
L = length of soil sample
A = cross-sectional area of soil sample
t = time elapsed
H_o = initial head
H_1 = final head

FIELD DETERMINATIONS OF HYDRAULIC CONDUCTIVITY

In situ permeability or hydraulic conductivity values of soils can be determined with tests carried out in a single borehole or piezometer. Tests are initiated by a sudden introduction of a known volume of water, which causes an instantaneous change in water level (or head).

where

W_{RW} = wet weight of refuse from excavation
V = volume of excavation determined by water displacement method

Dry density was then determined as follows:

$$\text{Dry Density} = \frac{\text{Wet Density}}{1.0 + \text{m.c.}}$$

where

m.c. = moisture content of refuse determined in the laboratory

Test methods used were modifications of the open-end test employed by the Bureau of Reclamation and U.S. Army Corps of Engineers. The test is made through the open end of a pipe casing that has been immersed to the desired depth. Testing begins by adding clear water through a metering system to maintain gravity flow at a constant head. The hydraulic conductivity is calculated from the equation:

$$K = \frac{Q}{(5.5)rH}$$

where

Q = constant rate of flow into the hole
r = internal radius of casing (4 in.)
H = differential head of water (2.5 ft for soils and 1.5 ft for refuse)

Typically, the test casing must extend a minimum of 10 times its radius into the soil horizon being evaluated. But the requirement to test cover soils of 1 ft total thickness necessitated a modification of that limitation. A well-placed bentonite seal was thus used to prevent leakage of water at the base of the testing pipe and ensure accurate readings. Figure A-1 illustrates the apparatus used for testing both the soil and the refuse.

FIELD DETERMINATION REFUSE DENSITY

The in-place density of refuse was estimated using the following procedure:

1. A smooth surface was prepared on the floor of the excavation.

2. Refuse was carefully removed by hand to form a cylindrical hole.

3. Approximately 30 lbs of refuse was carefully removed, placed in plastic bags, and weighed.

4. A plastic sheet was placed in the cylindrical excavation; the sheet was molded to conform as nearly as possible with the shape of the excavation.

5. The volume of the opening was estimated by pouring measured quantities of water into the plastic sheeting until the original refuse surface had been matched.

The wet density of the refuse was then calculated from the equation:

$$\text{Wet Density} = \frac{W_{Rw}}{V}$$

Appendix B

PROCEDURES USED IN CHEMICAL TESTING OF SOIL SAMPLES

This study included an evaluation of the distribution patterns of 13 chemical species in the soil beneath each test cell. The compounds and elements examined in this study were selected either because they are environmental pollutants (cadmium, chromium, copper, lead, mercury, nickel, zinc) or because they are highly concentrated in leachate and are therefore likely to be useful in tracing leachate movement (calcium, chloride, magnesium, sodium, sulfate, total Kjeldahl nitrogen). The procedures used to analyze the samples removed from the soil cores can be subdivided into two activities -- sample preparation and sample analysis.

SAMPLE PREPARATION

Sample preparation procedures differed according to the analysis to be performed, but generally they involved extraction, filtration, and concentration. Extraction refers to solubilization of the constituents present in the soil by contact with either water or an acid solution. All of the metals but mercury were subjected to both acid and water extraction procedures to distinguish between that portion of the metal content that is only slightly bound to the clay particles or contained in solution in the interstitial water, and that fraction that was more tightly adsorbed to the soil particles. The investigation was to determine how much of the various constituents of interest had been introduced into the soil by leachate movement. Most of the elements or compounds studied are naturally present in varying degrees in soil, as evidenced by the analytical results for the reference soils. Extraction techniques release the natural constituents in ever greater amounts as the severity of the procedure increases, thereby enhancing the likelihood that any contribution resulting from leachate penetration will be masked.

Initial testing of various acid types and strengths was conducted to find the most vigorous procedure that could be employed without releasing tolerable levels of metals from the native soil matrix. HCl and HNO_3 in strengths of 0.1N, 0.5N, 1.0N and 10N were examined. HNO_3 was found satisfactory for all metals studied except cadmium, which showed a 10-fold greater extraction with HCl. As expected, the concentration of constituents increased with acid strength, but appeared to optimize at approximately 1.0N. A 1:1 mixture of HNO_3:HCl at 1.0N concentration was therefore used in this study. Note that the choice was largely arbitrary, because no standard method exists for this type of analysis.

The complete solubilization/extraction procedure employed was as follows:

1. An aliquot of soil (one quarter of the sample for acid extraction, one for water) was placed in a 500 ml Erlenmeyer flask, and either 200 ml of deionized water or equimolar 1.0 N HCl/HNO_3 was added. The soils were broken apart with a glass rod and placed on a shaker for 2 hr.

2. The extracted soil suspension was filtered through a series of increasingly finer pore filters, terminating with passage through a 0.45-micron membrane filter to ensure that constituents were soluble and not particulate.

3. The filtrate was placed in a 250-ml volumetric flask and diluted to the mark with water. (The water extract was first acidified to about pH 4.0 to ensure heavy metal stability and to optimize conditions for the other APDC/MIBK extraction procedures.)

4. Fifty milliliters was removed and set aside to be analyzed for high concentration metals (Ca, Mg, Na). The 200 ml remaining was further processed to concentrate the low level metals by addition of 5.0 ml of 1.0% ammonium pyrolidine dithiocarbamic acid (APDC), a chelating agent.

5. Fifteen milliliters of methyl isobutyl ketone (MIBK) was added, and the mixture was shaken for 15 min.

6. The organic layer, containing the chelated metals, was drawn off by transfer pipet and passed through a phase separation paper (Whatman) to remove the water.

7. Appropriate standards were made up in similar fashion.

In general, the MIBK extract was used for the analysis of most of the water-extracted constituents and for the low-level metals (Cd, Cu, Cr, Ni, Pb, Zn) in the acid extracted samples. The 50 ml for the original filtered sample was used in the analysis of the high-level constituents such as Ca, Mg, Na, Cl. The treatment of the extract subsequent to the filtration is standard methodology; most of the procedures for the APDC/MIBK extraction are reported in the literature.

A potential problem encountered in this study was the possibility that total cation concentration was sufficiently high to saturate the APDC chelation sites, with resulting potential loss of recovery. This might be the reason why certain water extracts were found to be more reproducible with time than was the acid extract. In addition, the extract must be "dry," as the elements will tend to distribute between the aqueous and organic phases and produce erratic results when micelles of water are aspirated into the flame during atomic absorption analysis. Various methods were tried to eliminate this difficulty (e.g., sodium sulfate, etc.); but the final choice of phase separation paper proved the most effective and the least labor intensive. The remaining two quarters of a given core sample were used to determine sulfate, total Kjeldahl nitrogen, mercury content, and cation exchange capacity. The

procedures for these analyses are indicated in the analytical methods section that follows.

SAMPLE ANALYSIS

The samples were analyzed using standard procedures as listed below. Comments specific to each determination are appended where appropriate.

Chloride - Specific ion electrode on water solubilized portion of sample.

Heavy metals (Cd, Cr, Cu, Zn, Ni, Pb) - Atomic Absorption spectroscopy per procedures presented in Atomic Absorption Newsletter, 5(2); 17-18, 1966, as modified by current EPA methods.

Other metals (Ca, Mg, Na) - Atomic Absorption spectroscopy per Rand, M.C., et al., eds., Standard methods for the examination of water and wastewater, 14th ed., Washington, D.C., American Public Health Association, 1976.

Mercury - Direct digestion of the soil by strong acid, followed by flameless atomic absorption spectroscopy. The mercury analysis, when handled with care, is adequate for the determination of mercury at very low levels in soils. However, as the method is based on the total destruction of the soil matrix by strong acid oxidation, the presence of any native mercury would present problems.

Sulfate - Turbidometric analysis by barium sulfate addition, per method of the Agronomy Society.

Total Kjeldahl nitrogen (TKN) - Per EPA sediment analysis, protocol with Nesslerized finish. As presently formulated, the TKN analysis is probably not sufficiently reliable for direct application to soils. The variation in normal soil organics is perhaps sufficient to render interpretation difficult. Although TKN is often a significant parameter in leachates, it is such a nonspecific one that finding moderate levels beneath a fill would be of questionable diagnostic value.

Cation exchange capacity - per Peech, M.A., et al., Methods of soil analysis for soil fertility investigations, USDA Circular 757, Washington, U.S. Government Printing Office, 1947.